CARLSON

Bearing Power of Soils

Civil Engineering

B. S.

1911

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BEARING POWER OF SOILS

BY

PAUL CARLSON

THESIS

FOR THE

DEGREE OF

BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1911

UNIVERSITY OF ILLINOIS

May 25, 1911

I recommend that the thesis prepared under my supervision by PAUL CARLSON entitled The Bearing Power of Soils be approved as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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Recommendation approved:

Ira O. Baker.
Head of the Department of Civil Engineering.

OUTLINE.

INTRODUCTION.

PART 1.

DESCRIPTION OF TESTS AND TESTING APPARATUS.

PART 2.

DISCUSSION AND CONCLUSIONS.

PART 3.

SUGGESTIONS FOR FUTURE EXPERIMENTS.

INTRODUCTION.

One of the most important problems to be solved in the erection of the heavy structures of modern times is the design of the foundations; and as the form and area of these depend on the bearing capacity of the soil on which they rest, the bearing capacity becomes the determining factor of the design. The many failures which are due to defective foundations are mute witnesses to the fact that accurate data as to the allowable pressures on soils are scarce. The problem that confronts one who wishes to design a foundation is, therefore, the determination of the safe bearing capacity of the strata on which the structure rests.

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Two or three attempts have been made to solve this problem by means of theoretical consideration alone. Mr. Paiker developed a formula based on the mutual action of sliding and resistance prisms, and Mr. Rankine developed a formula based on the more modern theory of granular masses. These formulas do not give results that agree with pressures actually in use, and almost all engineers consider them as unreliable. It is said that more mathematical work has been done on the determination of the pressure exerted by earth against a retaining wall than onany other engineering problem; and even then the results are of doubtfull value. The condition of the earth is much more uniform behind a retaining wall than it is in a foundation; and if that problem cannot be solved by means of theoretical consideration, it does not seem probable that any criteria as to the safe bearing power of soils will be obtained by means of this method.

Tables showing the pressures actually used on foundations have

been compiled by many authorities, the most notable work along that line being the treatise on "Allowable Pressures on Deep Foundations" by Mr. E. L. Corthell. There are several classes of strata that are readily definable, such as ledge rock, hard pan, gravel, clean sand, dry clay, wet clay, and loam, and the tables have been arranged so as to give the allowable pressures on these classes. If the strata can really be placed under one of the above classes, and is of considerable thickness and area, it may be loaded with safety, according to the values given by Mr. Corthell. If the strata can not be classified or if peculiar conditions exist, it may be possible to find other structures which have been built with somewhat similar foundations, and the pressures used there can be assumed as safe. In either case, the safe way is to make an actual determination of the bearing capacity of the strata under consideration.

Considering the importance of the data obtained, few tests have been made; and it is the object of this thesis to collect the results of isolated tests and to draw some conclusions as to the proper interpretaion of the results. The various methods of performing the several tests will be described and a comparison will be made as to their relative merits.

THE BEARING POWER OF SOILS.

Few soil-tests have been made, and in most cases, the published results are very meager. The data in this thesis have been compiled from articles published in engineering papers, from the reports of engineering societies, and from tests conducted by the author. It consists of the results of tests, the description of the testing machines, a few notes on foundation failures and settlements, and conclusions.

Each test will be taken up separately, and for the purpose of reference, they will be considered in the following order, the name in each case being that of the structure for which the test was made, or the place at which it was made:

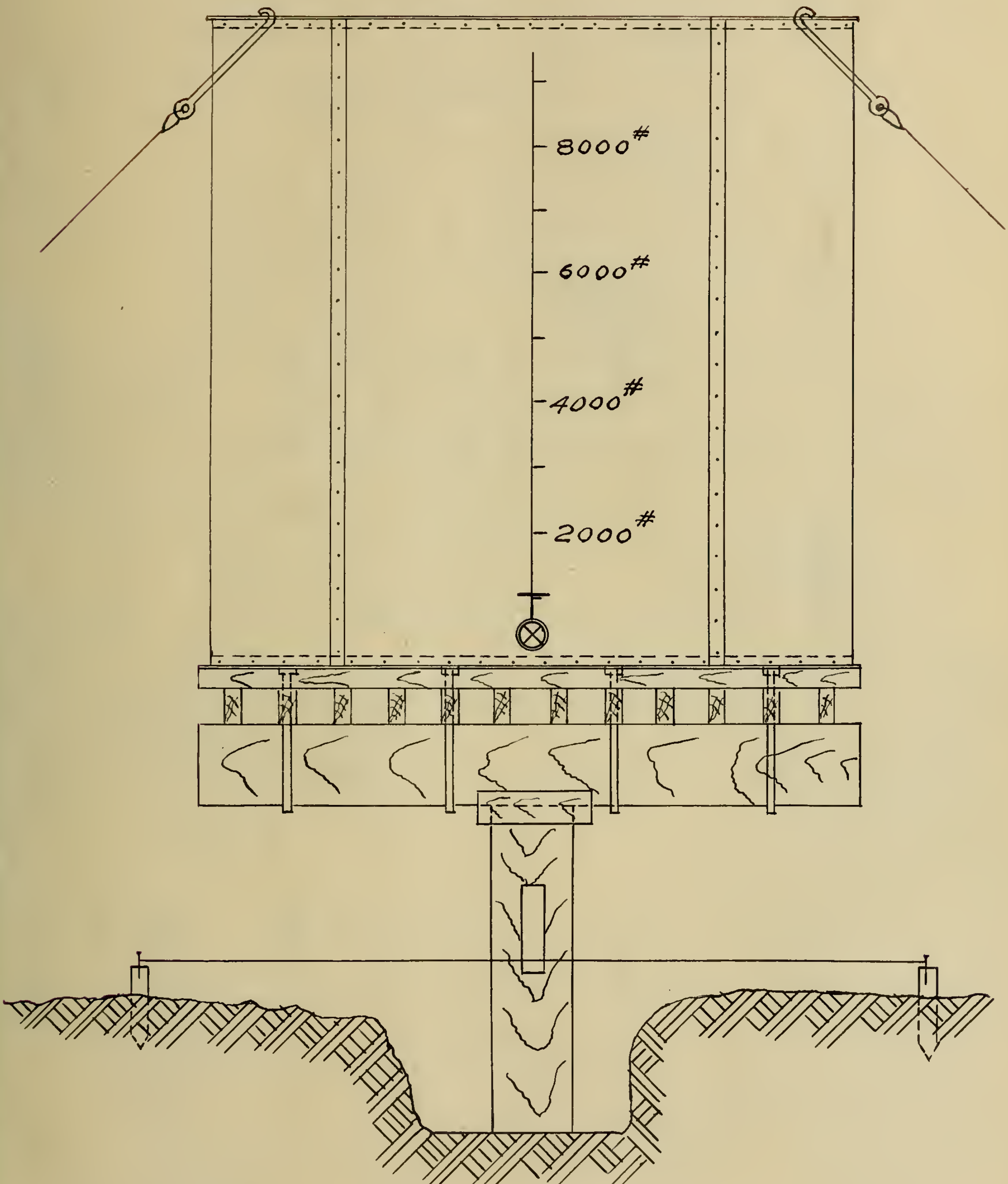
(1) Champaign, Illinois, by Paul Carlson; (2) Champaign, Illinois, by Avey and Shinn; (3) Municipal Building, New York, Preliminary Tests; (4) Municipal Building, New York, Final Tests; (5) St. Paul's Building, New York; (6) Masonic Temple, Chicago; (7) Capitol Building, Madison, Wis.; (8) County Bridge, Dallas, Texas; (9) State Capitol, Albany, New York; (10) New Orleans, Louisiana, by F. J. Llewellyn; (11) New Orleans, Louisiana, by John Roy; (12) Tyree Docks, England; (13) Barry Docks, England; (14) Hospital at Bercke, France; (15) Western Railway, France; (16) Exposition Building, Paris, France; (17) Church of Divine Paternity, New York; (18) Sand Foundation in New York; (19) Trader's National Bank, Toronto, Can.; (20) Exposition Buildings, Columbian Exposition, Chicago, Illinois; (21) State Capitol, Pierre, South Dakota; (22) East River Bridge, New York; (23) Government Printing Office, Washington, D. C; (24) Henry Worthington

Hydraulic Works, Harrison, New Jersey; (25) Testing Machine; (26) Testing Machine used by Mr. Brainard in Sand Foundations; (27) Settlement of Magistrates Court Building, British Guiana; and (28) Settlement of Homeopathic Hospital, Pittsburg, Pennsylvania.

(1) CHAMPAIGN, ILLINOIS.

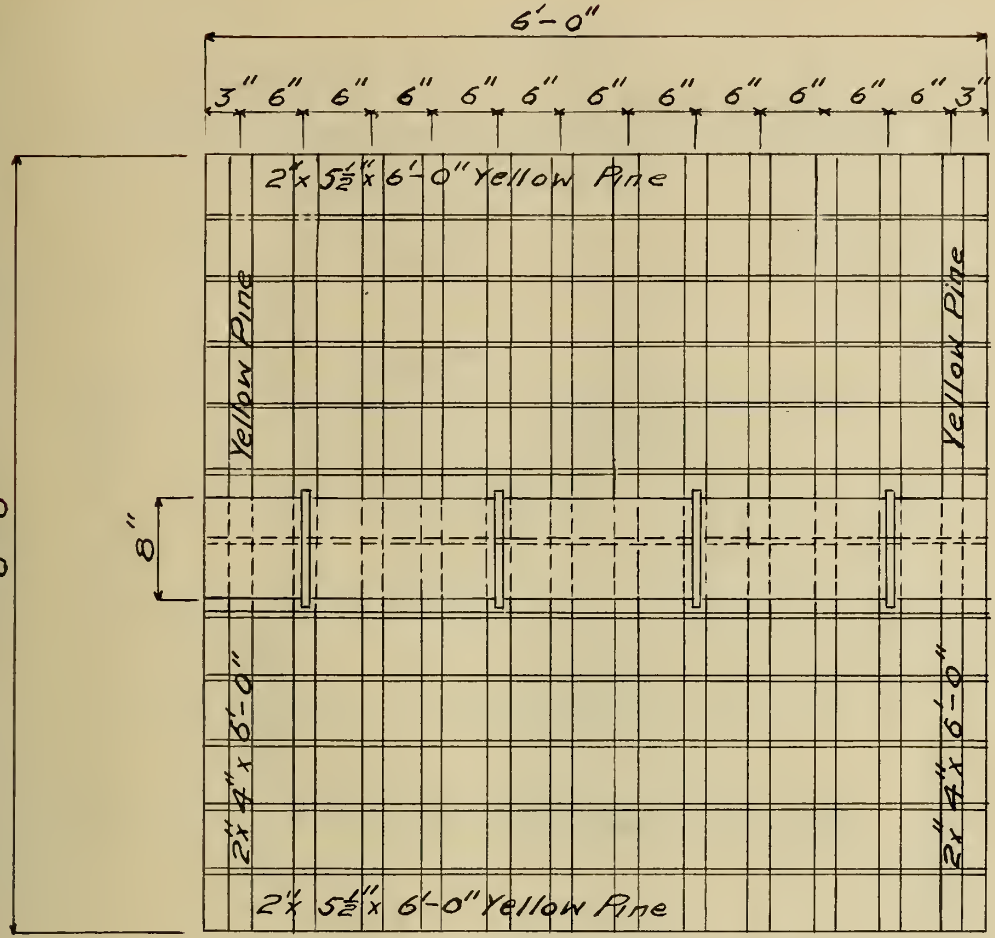
Two tests were conducted by the author to determine the bearing power of the stiff yellow clay underlying the surface soil of Champaign, Illinois. A pit, 2 1/2 ft. deep was dug and a horizontal surface was prepared. A mast, 8 inches square, carrying a loading platform was rested on this surface. The platform carried a tank, 6 ft. in diameter and 6 ft. deep, and the whole apparatus was kept vertical by means of guy wires which were attached to the tank. The apparatus is illustrated in Figs. 1, 2, and 3. The weight consisted of a known quantity of water contained in the tank. The water was assumed to weigh 62.5 lbs. per cu. ft., and a glass tube attached to the side of the tank was calibrated so as to give the weight of the water in the tank. The weight of the apparatus was known and the sum of these two weights gave the load imposed on the soil. A strip of zinc was nailed to the mast, and a fine steel wire was stretched across the face of this strip. The steel wire was attached to two stakes which were placed at such a distance from the mast that they could not be influenced by any movement of the apparatus. Before starting to fill the tank, a mark was made on the zinc strip, and the later settlements were measured from this mark with a steel scale. The two tests were conducted in exactly the same manner and the results agree very closely. The apparatus was set up and allowed to stand for 24 hours in order to avoid any initial settlement due to uneveness in the bearing surface. A zero reading was taken and the loading commenced. A load of 1464 lbs. was applied each day until the capacity of the tank was reached and the settlement due to each increment of load was noted. No rains fell during the tests. The results of these tests are given in Table 1 and 2 and in Diagrams 1 and 2.

Figure 1.

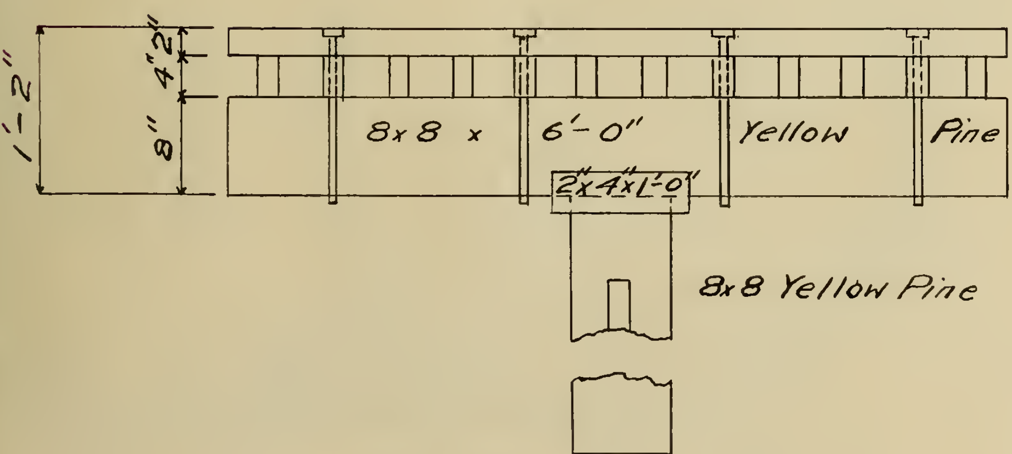


TESTING APPARATUS
USED IN
SOIL TESTS
AT
CHAMPAIGN ILL.

Figure 2.

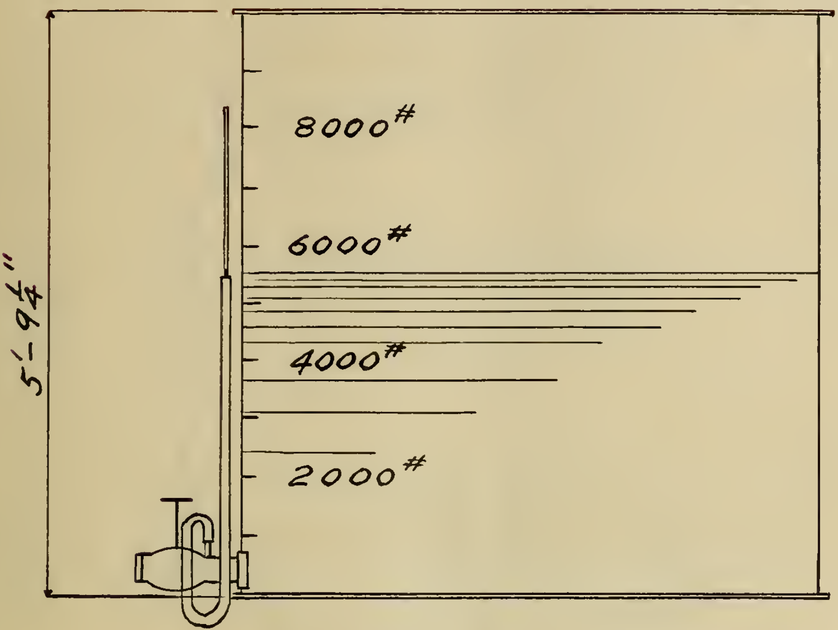


PLAN OF PLATFORM

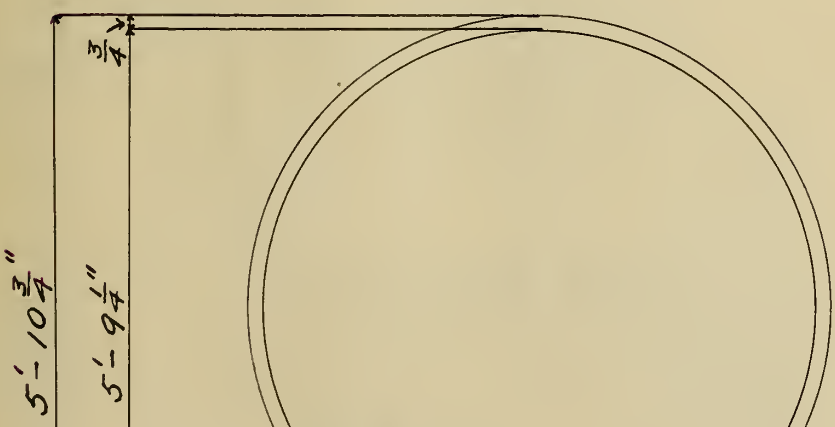


ELEVATION OF PLATFORM

Figure 3.



ELEVATION OF TANK



PLAN OF TANK

Table 1.

SOIL TESTS AT CHAMPAIGN, ILL., BY PAUL CARLSON

Test No. 1. Soil Tested:- Yellow Clay. Moisture:- 19.8%. Area Tested = 64 sq. in.

Date	Weight of Apparatus in pounds	Weight of Water Added in pounds	Total Weight in pounds	Pressure Tons per Sq. Ft.	Settlement Inches	Total Settlement Inches
Oct. 31, 5 P.M.	990	00	990	1.11	0.00	0.00
Nov. 1, 5 P.M.	990	1464	2454	2.76	0.09	0.09
" 2, "	990	2928	3918	4.46	0.17	0.26
" 3, "	990	4392	5382	6.06	0.35	0.61
" 4, "	990	5865	6855	7.72	0.29	0.90
" 5, "	990	7320	8310	9.36	0.43	1.33
" 6, "	990	8784	9774	11.01	0.92	2.25
" 7, "	990	8784	9774	11.01	0.00	2.25

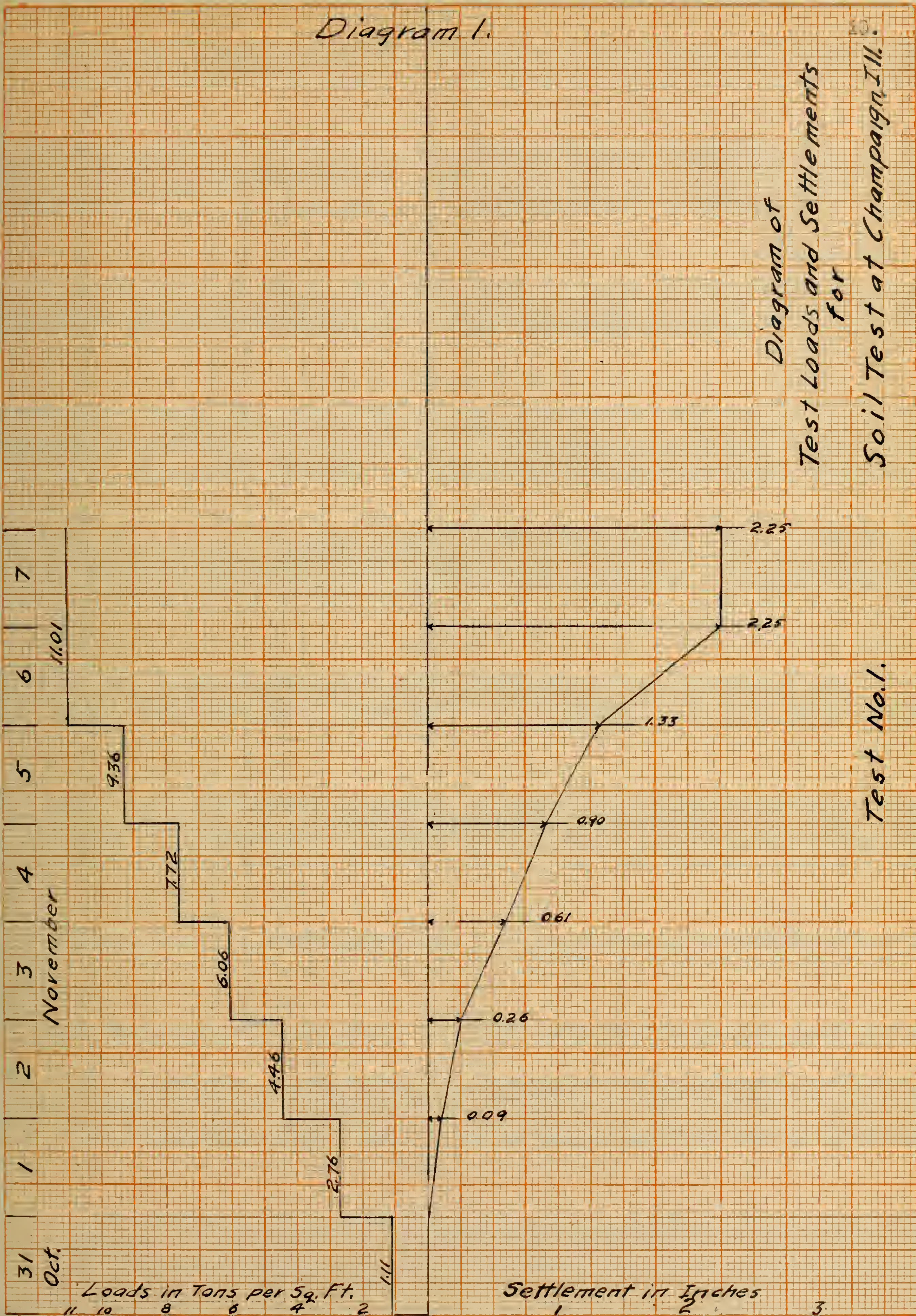


Diagram 1.
Diagram of
Test Loads and Settlements
for
Soil Test at Champaign, Ill.
Test No. 1.
Loads in Tons per Sq. Ft.
11 10 8 6 4 2
Settlement in Inches
0 1 2 3
Oct. 31
November
1 2 3 4 5 6 7
1.11
2.76
4.46
6.06
7.72
9.36
11.01
0.09
0.26
0.61
0.90
1.33
2.25
2.25
U. OF I. S. S. FORM 3

Table 2.

Test No. 2. Soil Tested:- Yellow Clay. Moisture:- 17%. Area Tested:- 64 sq. in.

Date	Weight of Apparatus in pounds	Weight of Water Added in pounds	Total Weight in pounds	Pressure Tons per Sq. Ft.	Settlement Inches	Total Settlement Inches
Nov. 7, 5 P.M.	990	00	990	1.11	0.00	0.00
" 8, "	990	00	990	1.11	0.00	0.00
" 9, "	990	1464	2454	2.76	0.08	0.08
" 10, "	990	2928	3918	4.41	0.13	0.25
" 11, "	990	4392	5382	6.06	0.36	0.61
" 12, "	990	5865	6855	7.72	0.28	0.89
" 13, "	990	7320	8310	9.36	0.40	1.29
" 14, "	990	8784	9774	11.01	0.91	2.20
" 15, "	990	8784	9774	11.01	0.00	2.20

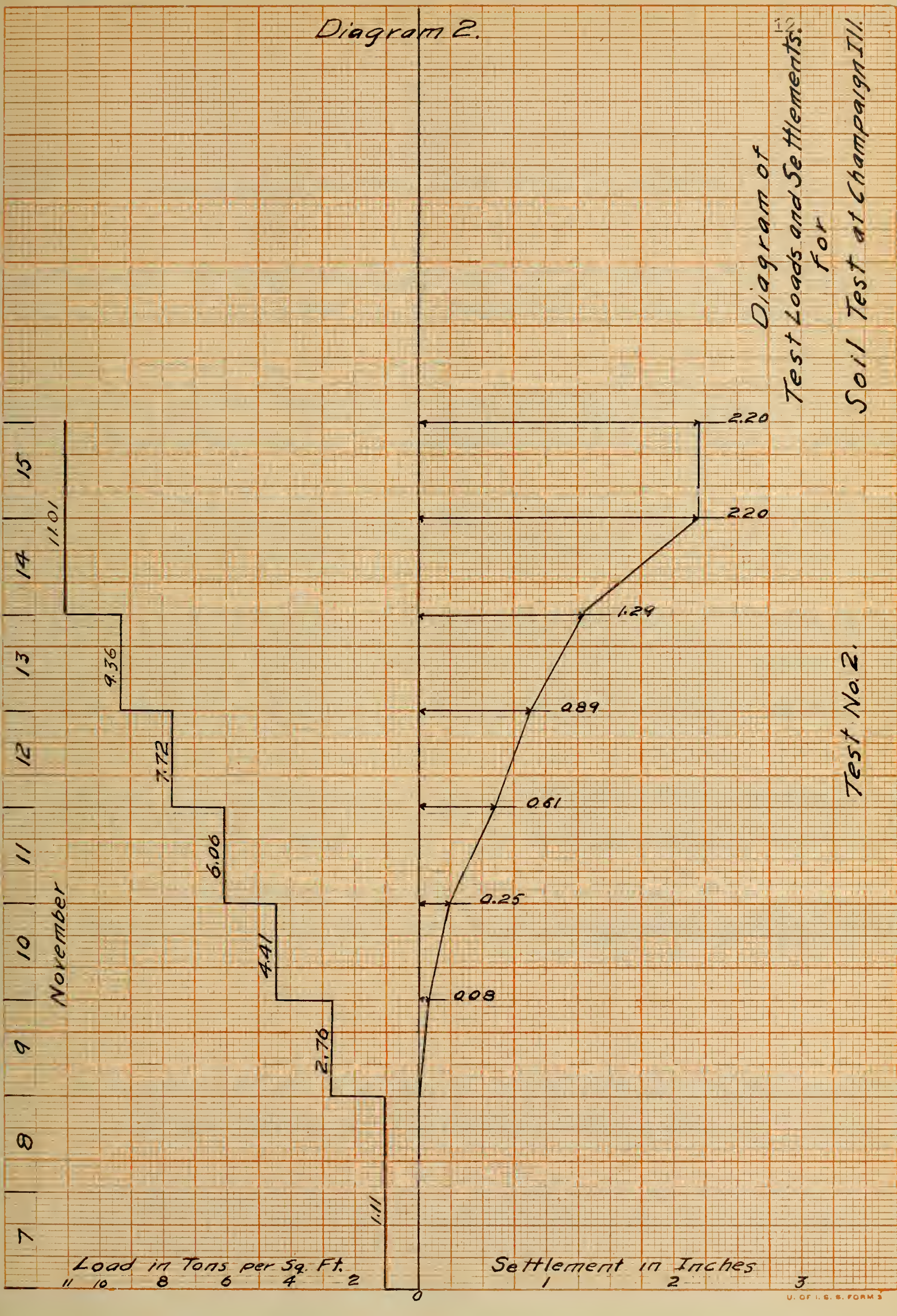


Diagram 2.
Diagram of
Test Loads and Settlements
for
Soil Test at Champaign Ill.
Test No. 2.
2.20
2.20
1.24
0.89
0.61
0.25
0.08
11.01
9.36
7.72
6.06
4.41
2.76
1.11
15
14
13
12
11
10
9
8
7
November
Load in Tons per Sq. Ft.
11
10
8
6
4
2
0
Settlement in Inches
1
2
3
U. OF I. S. S. FORM 3

(2) CHAMPAIGN, ILLINOIS.

In 1909 and 1910, tests of the bearing capacity of the soils in the vicinity of Champaign, Illinois, were conducted under the supervision of Messrs. Avey and Shinn. The apparatus was the same as was used in the tests previously described, and hence a further description is unnecessary. The first soil tested was the black alluvial soil overlying the land in the vicinity of Champaign. At the time of the test the soil was in a semi-dry state, and no rain fell during the test. The results of this test are given in Table 3, and as they are incomplete, no curve could be drawn. Avey and Shinn state that the settlement was uniform until the load reached 2.8 tons per sq. ft. and that after this the settlement was more rapid. They concluded that 2 1/2 tons per sq. ft. was the bearing capacity of the loam, and recommended 1 1/2 tons per sq. ft. as the value to be used in designing foundations. Tests Nos. 2 and 3 were obtained upon the stiff yellow clay underlying the surface soil. The tests were made at a depth of 2 ft. 8 in. below the surface. The results of these tests are given in Tables 4 and 5 and in Diagrams 3 and 4.

Messrs. Avey and Shinn gave the bearing capacity of the clay as 10 tons per sq. ft. and the safe working pressure as 5 tons per sq. ft.

SOIL TESTS AT CHAMPAIGN, ILL., BY AVEY & SHINN

Area tested:– 64 sq. in

Test No. 1. Soil Tested:– Black Loam Table 3

Date	Pressure Tons per Sq. Ft.	Settlement Inches	Rainfall Inches
May 12, '09	3.72	2.13	0.0
" 12 "	4.57	8.04	0.0

Test No 2 Soil Tested:– Yellow Clay Table 4

Date	Pressure Tons per Sq. Ft.	Settlement Inches	Rainfall Inches
May 24, '09	4.82	0.40	0.02
" 24 "	6.37	0.81	
" 25 "	6.45	1.37	1.22
" 26 "	6.80	1.53	1.82
" 27 "	6.80	2.67	
" 28 "	6.80	2.78	
" 29 "	6.80	2.80	
" 31 "	680	2.86	0.32
June 3, "	6.85	2.88	0.65
" 4 "	6.80	2.89	
" 4 "	6.80	2.89	
" 5 "	9.10	3.32	
" 6 "	9.10	3.70	
" 7 "	9.10	6.75	

Diagram 3

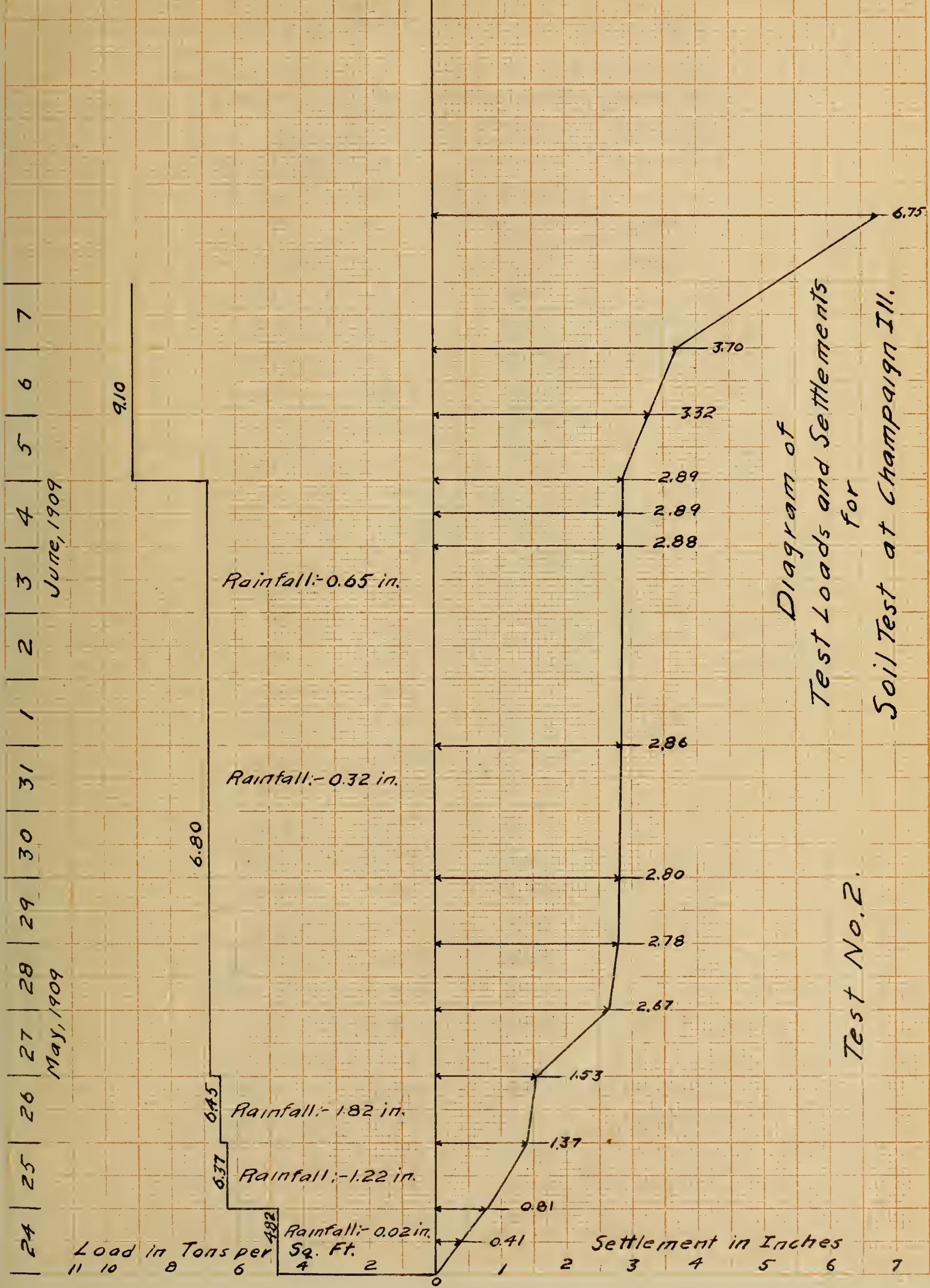


Diagram of
Test Loads and Settlements
for
Soil Test at Champaign Ill.
Test No. 2.
June, 1909
May, 1909
Load in Tons per Sq. Ft.
Settlement in Inches
Rainfall:- 0.65 in.
Rainfall:- 0.32 in.
Rainfall:- 1.82 in.
Rainfall:- 1.22 in.
Rainfall:- 0.02 in.
9.10
6.80
6.45
6.37
4.82
6.75
3.70
3.32
2.89
2.89
2.88
2.86
2.80
2.78
2.67
1.53
1.37
0.81
0.41

Table 5

Test No. 3 Soil Tested:- Yellow Clay

Date	Pressure Tons per Sq. Ft.	Settlement Inches	Rainfall Inches
Nov. 10, '09.	1.11	0.00	
" 10 "	4.71	0.47	
" 11 "	4.71	0.74	0.09
" 12 "	4.77	0.79	0.41
" 13 "	4.77	0.85	
" 14 "	4.77	0.90	0.20
" 15 "	4.77	0.90	0.11
" 15 "	4.83	0.90	
" 15 "	5.60	0.90	
" 15 "	6.16	1.00	
" 15 "	6.72	1.17	
" 16 "	6.95	2.27	1.09
" 17 "	6.95	2.42	
" 18 "	6.95	2.50	
" 19 "	6.95	2.52	
" 20 "	6.95	2.54	
" 21 "	6.95	2.55	
" 22 "	6.95	2.55	0.55
" 28 "	6.95	2.70	
" 30 "	6.95	2.70	
" 30 "	7.85	2.77	
" 30 "	8.99	2.97	
" 30 "	9.55	3.40	
" 30 "	10.10	3.92	
" 30 "	11.25	4.83	
Dec. 1, '09.	11.25	6.00	
" 2 "	11.25	6.20	0.04
" 3 "	11.25	6.20	
" 4 "	11.25	6.21	0.09
" 5 "	11.25	6.21	0.25
" 6 "	11.25	6.22	
" 7 "	11.25	6.26	0.65
" 8 "	11.25	6.26	

Diagram 4

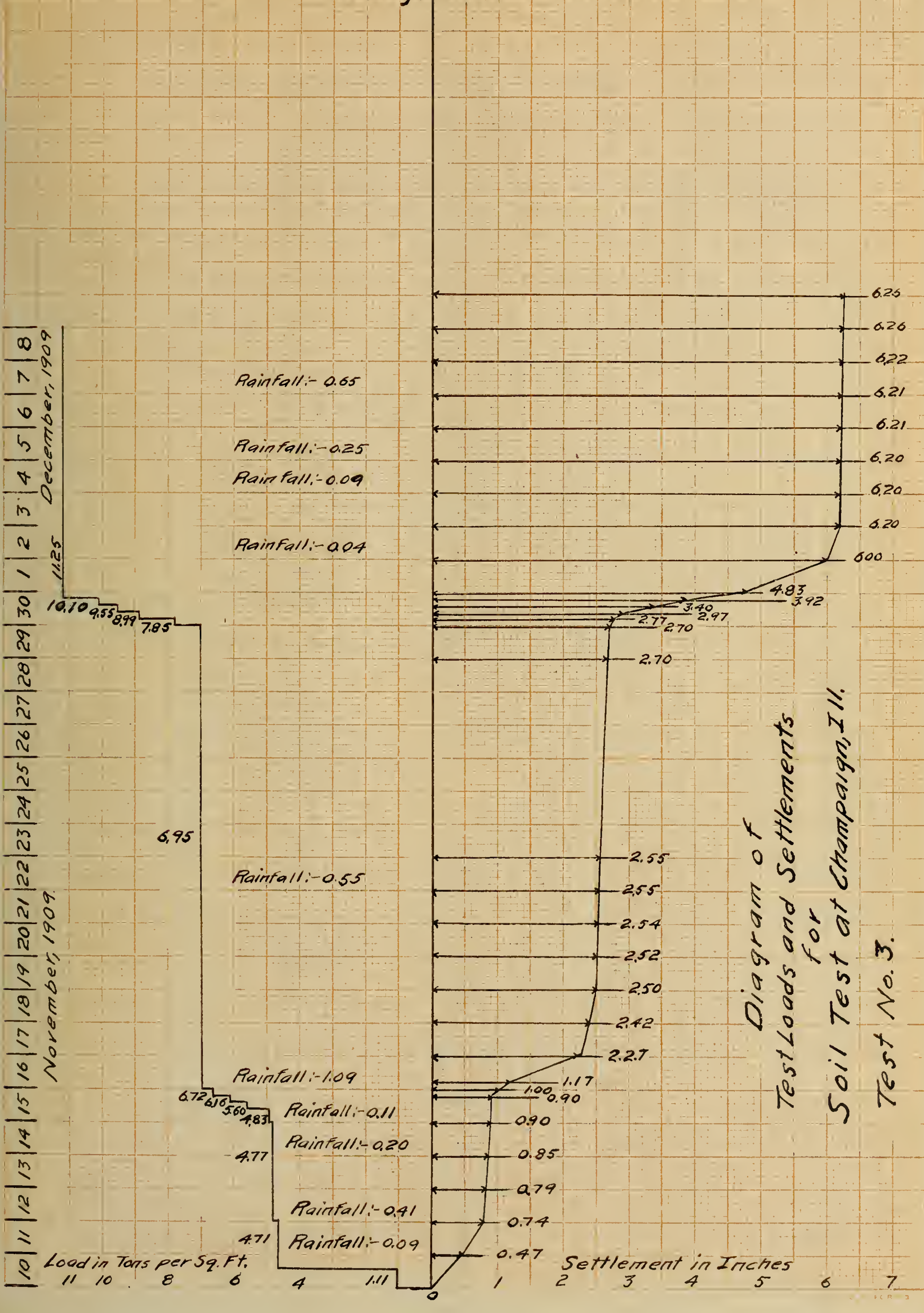


Diagram of
Test Loads and Settlements
for
Soil Test at Champaign, Ill.
Test No. 3.
November, 1909.
December, 1909
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1 2 3 4 5 6 7 8
Load in Tons per Sq. Ft.
11 10 8 6 4
Settlement in Inches
0 1 2 3 4 5 6 7
1.11
4.71
4.77
4.83
5.60
6.16
6.72
6.95
7.85
8.99
9.55
10.10
11.25
Rainfall:- 0.09
Rainfall:- 0.41
Rainfall:- 0.20
Rainfall:- 0.11
Rainfall:- 1.09
Rainfall:- 0.55
Rainfall:- 0.04
Rainfall:- 0.09
Rainfall:- 0.25
Rainfall:- 0.65
0.47
0.74
0.79
0.85
0.90
0.90
1.00
1.17
2.27
2.42
2.50
2.52
2.54
2.55
2.55
2.70
2.70
2.77
2.97
3.40
3.92
4.83
6.00
6.20
6.20
6.20
6.21
6.21
6.22
6.26
6.25

(5) MUNICIPAL BUILDING, NEW YORK.

PRELIMINARY TESTS.

The Municipal Building in New York was designed by the firm of McKim, Mead, and White. Due to the extreme depth to rock, it was decided to found the structure upon a layer of sand overlying the rock. Tests of the bearing capacity of this sand were made as follows:-

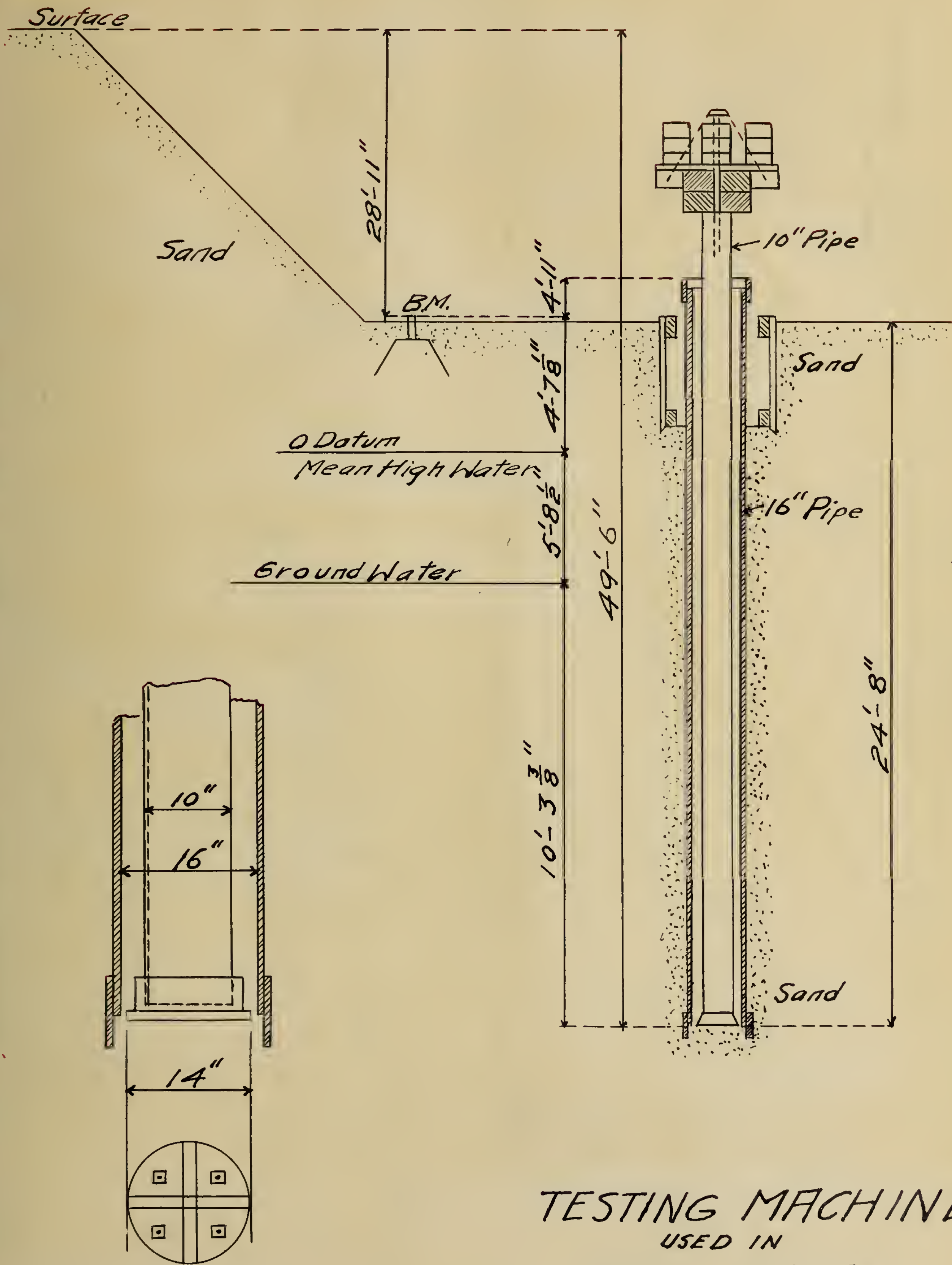
"Wash-borings at the site of the twenty-five story municipal building at Park Row and Chambers Street, New York City, indicated a deposit of course sharp sand to a depth of 50 feet, and then fine sand to a depth of 150 feet below the street. Tests of the bearing capacity of the sand were conducted under the supervision of Mr. J. F. O'Rourke who designed the apparatus that was used.

""A heavy 16-inch steel pipe in sections, coupled together with outside screwed sleeves, was sunk by water jet and steam hammer from elevation 0 at the bottom of a small sheeted excavation to elevation 16 at a depth of 49 1/2 feet below the surface of the street. The sand was removed from the pipe by a bucket made of a 10-inch pipe with a check valve at the lower end. A 10-inch steel pipe with the lower end closed by a 14-inch ribbed cast-iron disc was inserted in the 16-inch pipe and revloved on its vertical axis until the disc ribs cut a satisfactory bearing on the sand at the bottom. The upper end of the pipe was centered by fillers inside the 16-inch pipe and projected several feet above the latter to support a timber platform clamped to it clear of the 16-inch pipe, and guyed to a flange collar at the top of the 10-inch pipe. This apparatus is illustrated in Fig. . The platform was loaded with pig iron and with cast-iron blocks such as are used for caisson

sinking, which were carefully and symmetrically applied at intervals of a few days, and the corresponding settlements were accurately measured by leveling on a reference mark on the 10-inch pipe and on a bench mark established at about the same elevation and far enough away to be free from any displacement. The ground-water level was determined by direct measurement in the 16-inch pipe. In test No. 1 the disc at the foot of the 10-inch pipe took bearing on the sand 7 inches above the lower edge of the outside coupling which formed a cutting edge and projected below the bottom of the 16-inch pipe. As the inside of this coupling was threaded, it was thought that it might have sufficient friction on the sand to make it arch and relieve the pressure on the sand below. Consequently, after the completion of the test the pipe was pulled up and the coupling screwed up with the bottom edge flush with that of the pipe, leaving a continuous smooth interior surface, and the pipe was redriven for test No. 2 and 3."

The results of these tests are given in Diagrams 5, 6 and 7. These results were considered to indicate that, with gradually applied load, the sand had a bearing capacity in the neighborhood of 20 tons per sq. ft., within the bounds of reasonable settlement, and the building was designed to have 116 caissons carried down to 60 feet below the street. These piers would impose a pressure of 8 tons per sq. ft. on the sand. Later the design was changed to 106 caissons carried down to 72 feet below the street, which imposed a pressure of 6 tons per sq. ft. on the sand.

Figure 4



TESTING MACHINE
USED IN
SOIL TESTS
FOR
MUNICIPAL B'L'D'G NEW YORK

Details of Plunger
Used in Test No. 1

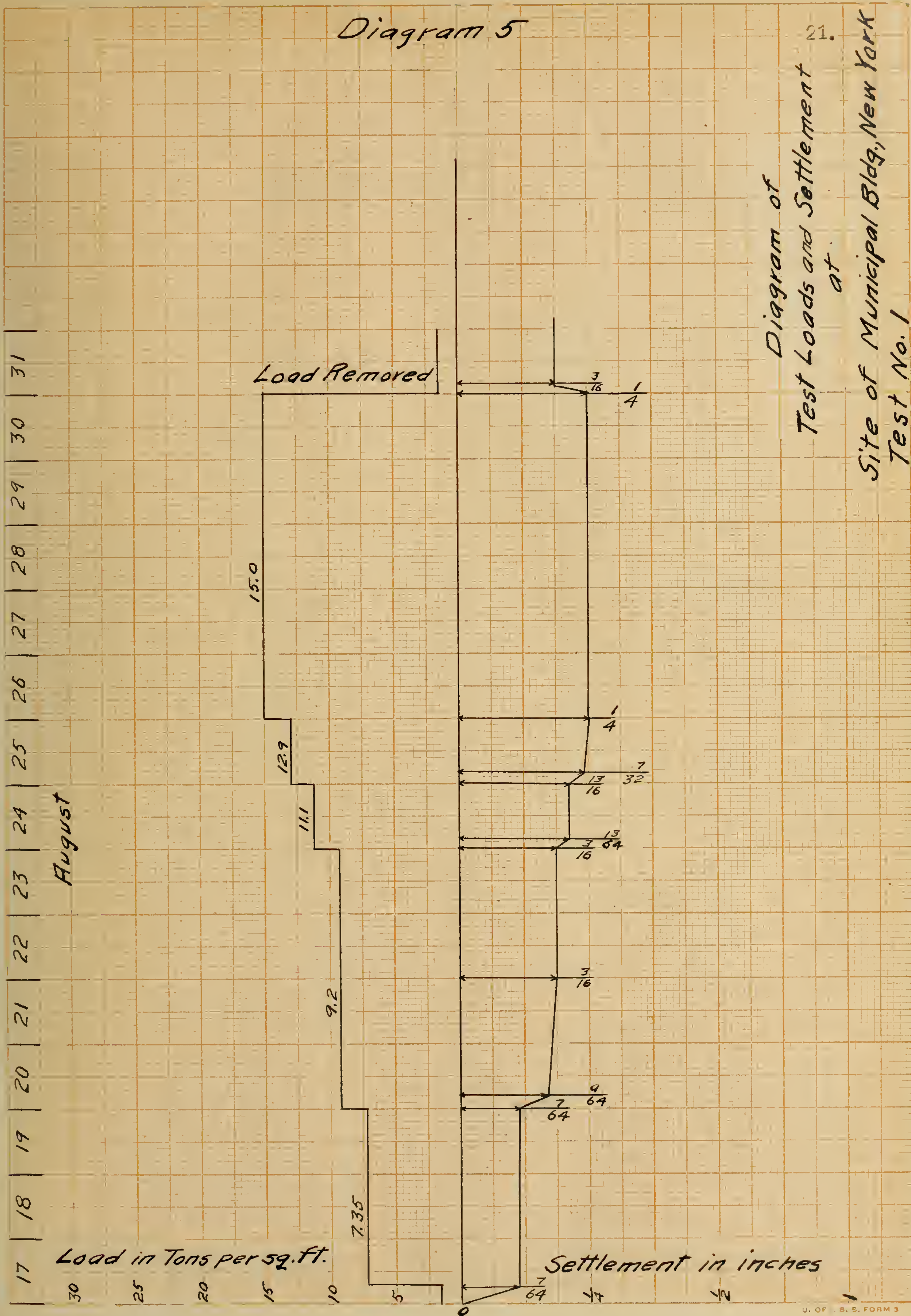


Diagram 5
Diagram of
Test Loads and Settlement
at
Site of Municipal Bldg., New York
Test No. 1
Load Removed
15.0
12.9
11.1
9.2
7.35
August
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
Load in Tons per sq. ft.
30
25
20
15
10
5
0
Settlement in inches
1/4
1/2
7/64
9/64
3/16
13/64
13/16
7/32
1/4
3/16
U. OF I. S. S. FORM 3

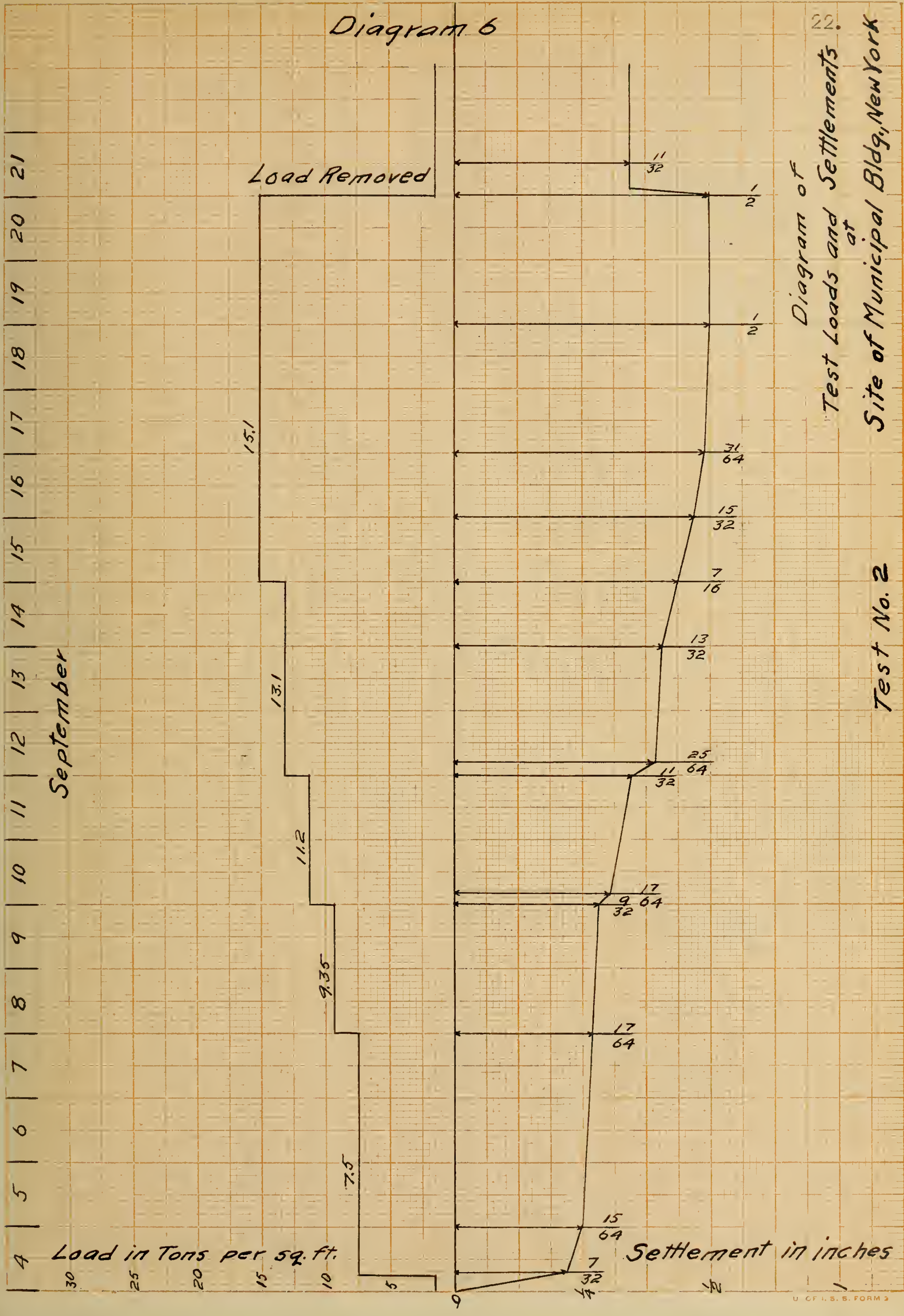


Diagram 6
Diagram of Test Loads and Settlements at Site of Municipal Bldg., New York
Test No. 2
Load Removed
September
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
15.1
13.1
11.2
9.35
7.5
5
Load in Tons per sq. ft.
30 25 20 15 10 5
Settlement in inches
0 1/4 1/2 1
7/32
15/64
17/64
9/32
17/64
11/32
25/64
13/32
7/16
15/32
31/64
1/2
1/2
11/32
U. OF I. S. S. FORM 3

Diagram 7

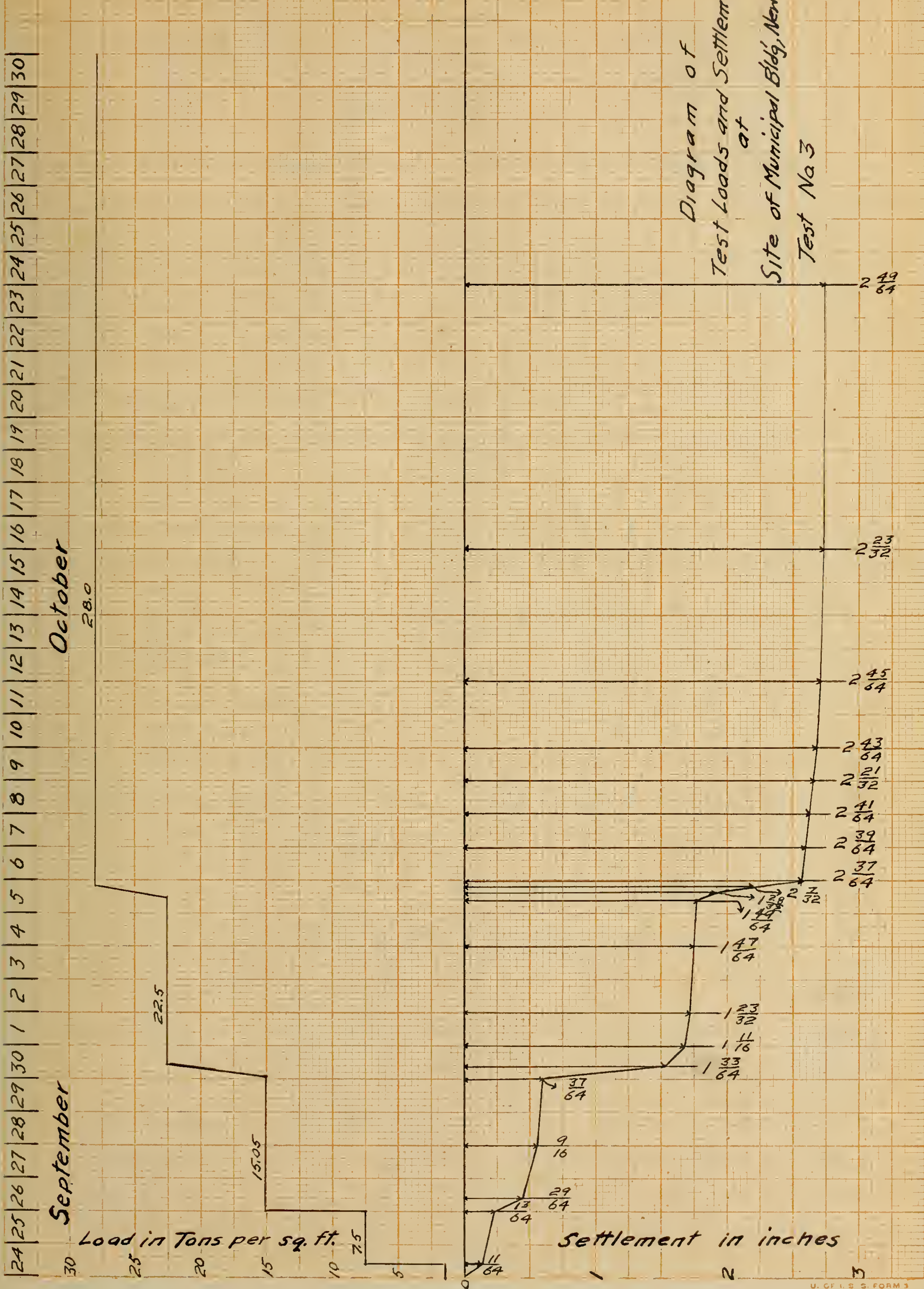


Diagram of
Test Loads and Settlements
at
Site of Municipal Bldg, New York
Test No 3
September
October
Load in Tons per sq. ft.
Settlement in inches
30 25 20 15 10 5 0
1 2 3
7.5
15.05
22.5
28.0
11/64
13/64
29/64
9/16
37/64
1 33/64
1 11/16
1 23/32
1 47/64
1 49/64
1 27/32
2 7/32
2 37/64
2 39/64
2 41/64
2 21/32
2 43/64
2 45/64
2 23/32
2 49/64
24 25 26 27 28 29 30 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
U. OF I. S. S. FORM 3

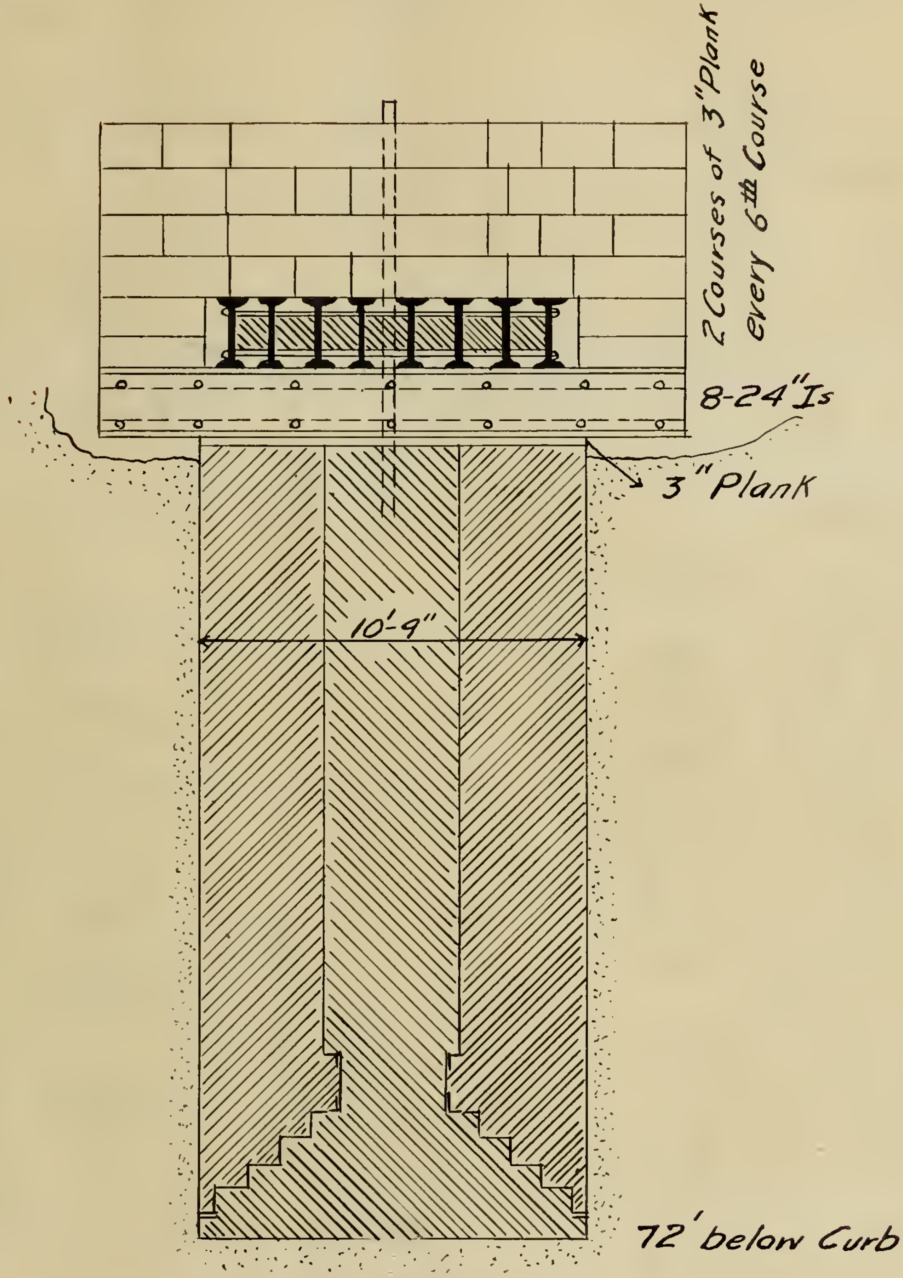
(4) MUNICIPAL BUILDING, NEW YORK.

FINAL TESTS.

"In order to verify the results of the comparatively small bearing tests by the action of a full sized pier under a heavy load, one of the finished piers was subjected to a test load considerably in excess of its maximum working load, and very careful records of its settlement were kept. As skin friction is proportionally less for large piers, one of the largest was chosen. The one chosen was also one of the shortest, again diminishing skin friction. Pier 120 is 10 feet 9 inches in diameter and 54 feet 5 inches long, with the cutting edge 72 feet below the street. The manner of applying the load to the pier is shown in Fig. 5.. The test was made according to the following instruction:- "Apply an initial load of 2 tons per sq. ft. to the caisson. Thereafter every 24 hours apply a further load of one ton per sq. ft. until the load reaches 6 tons per sq. ft. Permit load of 6 tons per sq. ft. to remain for 7 days and then apply a load of one ton per sq. ft; thereafter every 24 hours apply a further load of one ton per sq. ft. until the total load equals 10 tons per sq. ft. This load shall remain on the caisson for a period of 7 days when the whole load shall be expeditiously removed. The load shall be applied so as to cover uniformly the the whole area of the caisson." The test was carried out according to these instructions with the results given in Table 6 and in Diagram 6. From these it will be seen that the increments of one ton per sq. ft. produced immediate increments of settlement by .005 to .010 ft, which in the interval of 24 hours were increased by .002 to .004 ft. making total settlements from .006 to .014 ft. for each one ton loading. It

will also be noted that the total settlement for the working load of 6 tons per sq. ft. was only a scant 7/16 inch after this load had been applied 7 days, and that under this load the pier had such stability that the next application of an increment of one ton per sq. ft. produced no immediate settlement and only produced a settlement of .004 ft. after 24 hours. The total settlement immediately after the last increment which increased the total load to 10 tons per sq. ft. was only .004 ft. and after 7 days the total settlement was only 15/16 inch."

Figure 5



TEST LOAD
on
Pier 12C Municipal Bldg
New York New York

Table 6

Loading Test, Pier 12C Municipal Bldg. New York
Circular Pier. Diameter = 10 ft 9 in. Area = 90.76 sq. ft.

Date 1910	Total Load in Tons	Total Load in Tons per sq. ft.	Settlement		
			For each increment		Total
			Immediate	Additional	
Sept. 8	0	0	0	0	0
" 9	181.6	2	.007	---	.007
" 10	"	2	---	.003	.010
" 10	272.4	3	.005	---	.015
" 12	"	3	--	.002	.017
" 12	363.2	4	.007	--	.024
" 13	"	4	--	.004	.028
" 13	454.0	5	.006	--	.034
" 14	"	5	--	.000	.034
" 14	544.8	6	Not Recorded	--	.034
" 21	"	6	--	.008	.042
" 21	635.6	7	.000	--	.042
" 22	"	7	--	.004	046
" 22	762.4	8	.003	--	.049
" 23	"	8	--	.003	.052
" 23	817.2	9	.009	--	.061
" 24	"	9	--	.004	.065
" 24	908.0	10	.004	--	.069
Oct. 1	"	10	--	.010	.079

Diagram 8

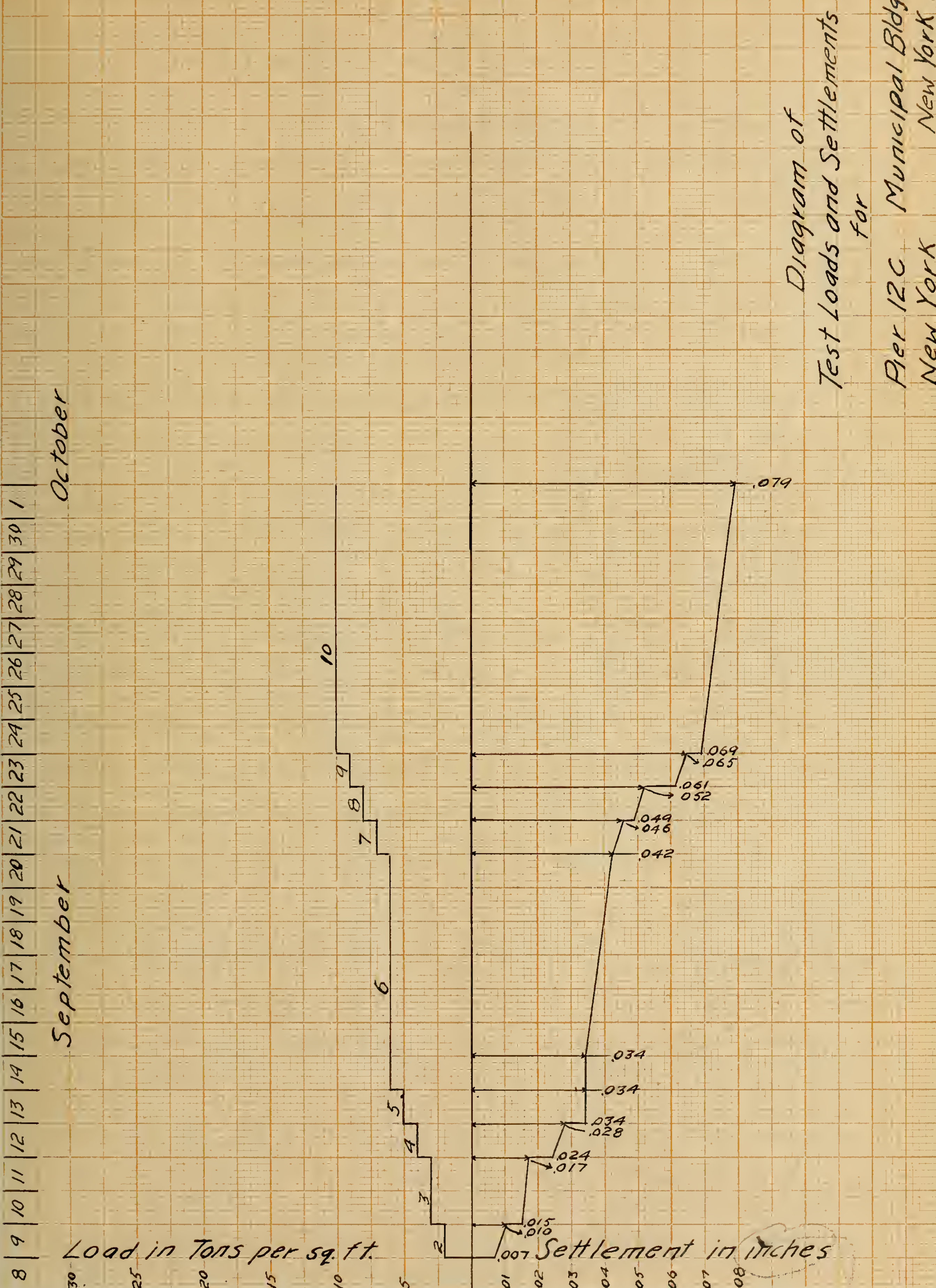


Diagram of
Test Loads and Settlements
for
Pier 12C Municipal Bldg
New York New York
October
September
1
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
Load in Tons per sq. ft.
Settlement in inches
30
25
20
15
10
5
0
.01
.02
.03
.04
.05
.06
.07
.08
10
9
8
7
6
5
4
3
2
.079
.069
.065
.061
.052
.049
.046
.042
.034
.034
.034
.028
.024
.017
.015
.010
.007

(5) ST. PAUL'S BUILDING, NEW YORK.

The St. Paul's Building at Broadway and Ann Street, New York, was one of the first of the modern tall buildings. Borings showed that bed rock was at a depth of 86 feet below the curb, and it was decided that the cost of sinking caissons to bed rock was prohibitive. Piles were not considered adequate to support the great weight of the building and consequently it was founded on an extremely fine, compact, clean sand, 52 feet below the curb. A well, driven on the site and pumped dry, failed to show any flow of sand.

A layer of concrete, 12 inches thick, was deposited over the whole area and the building rested on steel grillages placed on this concrete. The pressure on the soil was 5.2 tons per sq. ft. This pressure was expected to produce a settlement of 5/8 inch. This foundation was adversely criticised, and Mr. Post, the architect, requested that an examination of the foundations be made by expert engineers, and the services of Mr. Charles MacDonald and Mr. Theodore Cooper were secured for this purpose. The examination was made as follows:- A mast, one foot square, carrying a loading platform, was set up in a hole, 14 inches square, cut in the concrete. The loadings of the platform and the resulting settlements are given in Table 7 and in Diagram 9. During the test the mast was oscillated and water was poured into the test-pit so as to increase the settlement. When the load had reached 6 1/2 tons per sq. ft., a second hole was cut through the concrete, 4 1/2 ft. from the first one. Water was then poured into the first hole until it showed evidences of rising in the second hole. This did not cause any settlement or flow of sand. From the results of this test, the committee concluded that the foundations were safe.

Soil Test at Site of St Paul B'ld'g. New York

Soil Tested:- Sand   Area Tested:- 1 Sq. Ft.

3% clay in Sand   Table 7.

Date	Load in lbs/sq.ft.	Settlement in inches
Mch. 26, 1:10 P.M.	1500	0
" 1:25 "	4000	$\frac{1}{8}$
" 1:40 "	6000	$\frac{3}{16}$
Left 24 hrs.		
Mch. 27, 1:45 P.M.	6000	$\frac{3}{16}$
" 2:10 "	10000	$\frac{5}{16}$
Left 22 hrs.		
Mch. 28, 12 M	10000	$\frac{3}{8}$
Left 3 da.		
Mch. 31, 1:15 P.M.	10000	$\frac{3}{8}$
" 1:35 "	13000	$\frac{15}{32}$
Left 2 da.		
Apr. 2, 2:00 P.M.	13000	$\frac{9}{16}$
Left 4 da.		
Apr. 6, 5:00 P.M.	13000	$\frac{19}{32}$
Left 2 da.		
Apr. 8, 1:00 P.M.	13000	$\frac{19}{32}$

Diagram 9

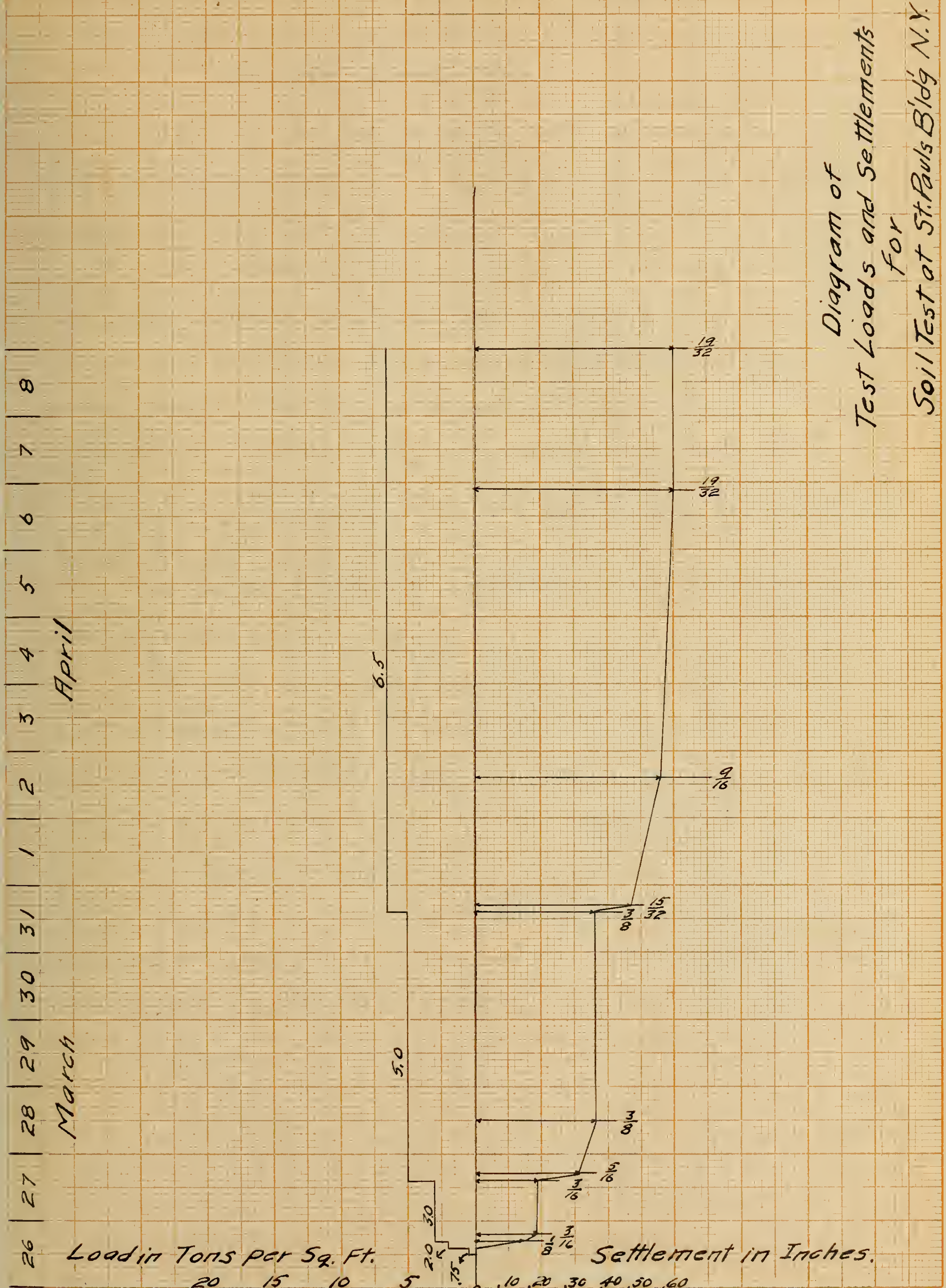


Diagram of
Test Loads and Settlements
for
Soil Test at St. Pauls B'ld'g N.Y.
March
April
26
27
28
29
30
31
1
2
3
4
5
6
7
8
Load in Tons per Sq. Ft.
20
15
10
5
0
.75
2.0
3.0
5.0
6.5
Settlement in Inches.
.10
.20
.30
.40
.50
.60
1/8
3/16
3/16
5/16
3/8
3/8
15/32
9/16
19/32
19/32
U. OF I. S. S. FORM 3

(6) MASONIC TEMPLE, CHICAGO.

At the time the Masonic Temple in Chicago was built, the open caisson method of sinking piers was undeveloped, and the building was founded on a layer of hardpan. The bearing power of this soil was of a very doubtful nature, and before construction was begun, two tests of its bearing capacity were made. A tank was supported on a plate, having an area of 2 sq. ft. and the load was applied by filling the tank with water. Test No. 1 was made on the surface of the hardpan while test No. 2 was made at a depth of 2 ft. 4 in. below the surface of the hardpan. The results of these tests are given in Tables 8 and 9 and in Diagrams 10 and 11.

General Sooy Smith, in an article on foundations published in the Proceedings of the Western Society of Engineers, says that the Chicago clay will begin to yield under a load of 2 tons per sq. ft. If the load remains constant the settlement will cease, but if the load is increased beyond this limit, settlement will be continuous. Diagram 11 seems to show that this is true. When the load reached 2.16 tons per sq. ft., the settlement was comparatively slow, and if this load had been allowed to remain for some time, it would undoubtedly have ceased, but when the load reached 2.81 tons per sq. ft. the settlement increased rapidly and was continuous until the test was abandoned.

Soil Tests at Site of Masonic Temple, Chicago, Ill.

Material Tested:- Hard-pan Area Tested:- 2 Sq. Ft.

Test 1; Bearing Area directly on Hard-pan

Date	Load in lb. per sq. ft	Settlement in inches
Oct. 10, 10 A.M.	267	0
" 2 P.M.	2226.5	$\frac{1}{4}$
Oct 11, 10 A.M.	4675.5	$\frac{11}{16}$
Oct. 13, 4 P.M.	5655.0	$1\frac{9}{16}$
Oct. 14, 5 P.M.	5655.0	$1\frac{13}{16}$

Table 8

Test 2; Bearing Area in Hole 2'-4" deep.

Date	Load in lb. per sq. ft.	Settlement in inches
Oct. 18, 4 A.M.	334.0	0
Oct 20, 9 A.M.	1327.0	$\frac{5}{8}$
" , 2 P.M.	2280.0	$\frac{7}{8}$
" , 3:30 P.M.	2965.0	$1\frac{1}{16}$
" , 4:30 P.M.	3767.0	$1\frac{3}{8}$
Oct 21, 9 A.M.	4311.5	$1\frac{15}{16}$
" , 1 P.M.	4934.0	$2\frac{1}{8}$
" , 5 P.M.	5627.5	$2\frac{13}{16}$
Oct 24, 8 P.M.	5627.5	$4\frac{1}{8}$

Table 9

Diagram 10

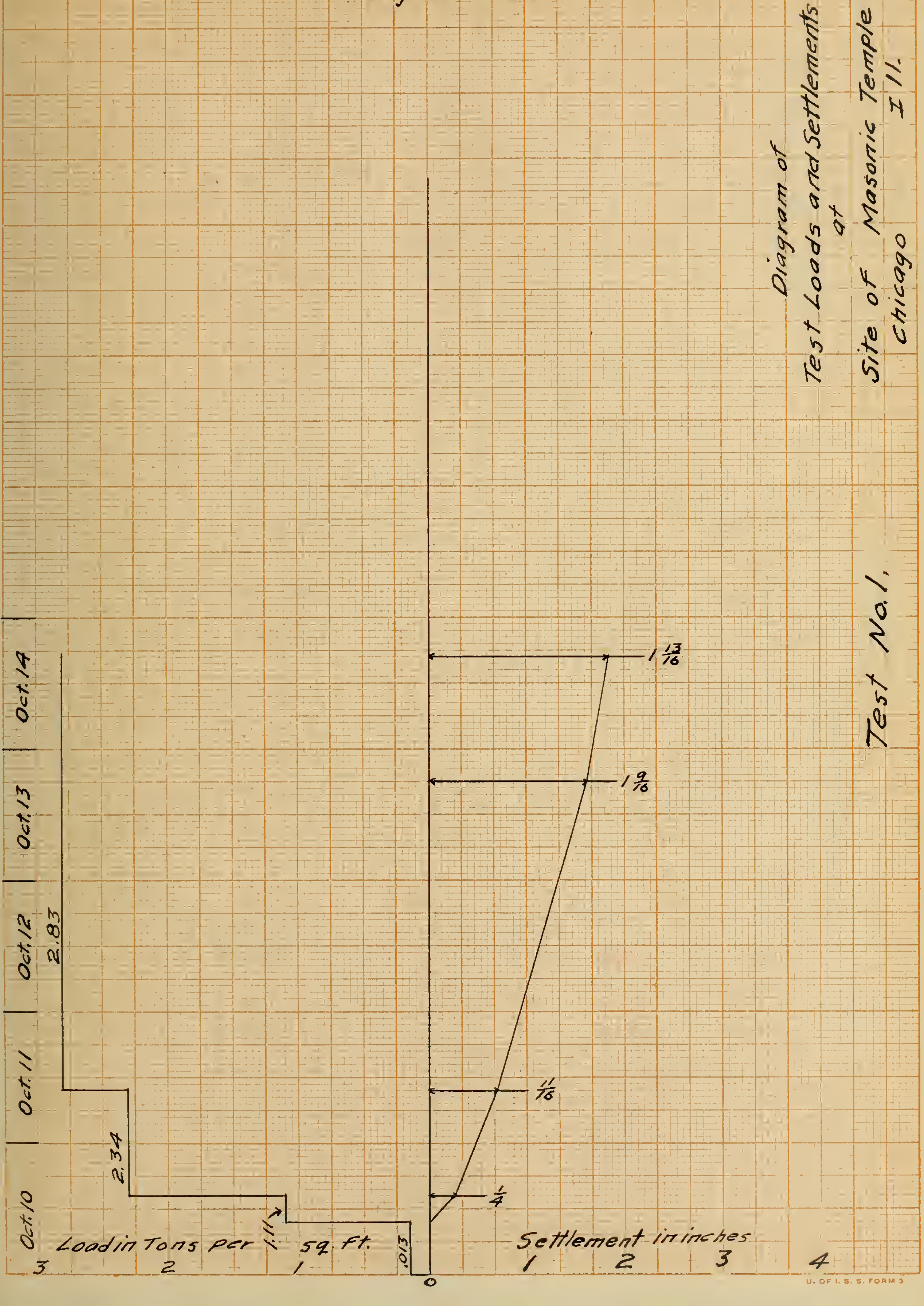


Diagram of
Test Loads and Settlements
at
Site of Masonic Temple
Chicago Ill.
Test No. 1.
Oct. 10
Oct. 11
Oct. 12
Oct. 13
Oct. 14
2.83
2.34
1.11
.013
1 13/16
1 9/16
11/16
1/4
Load in Tons per sq. ft.
Settlement in inches
3
2
1
0
1
2
3
4
U. OF I. S. S. FORM 3

Diagram 11

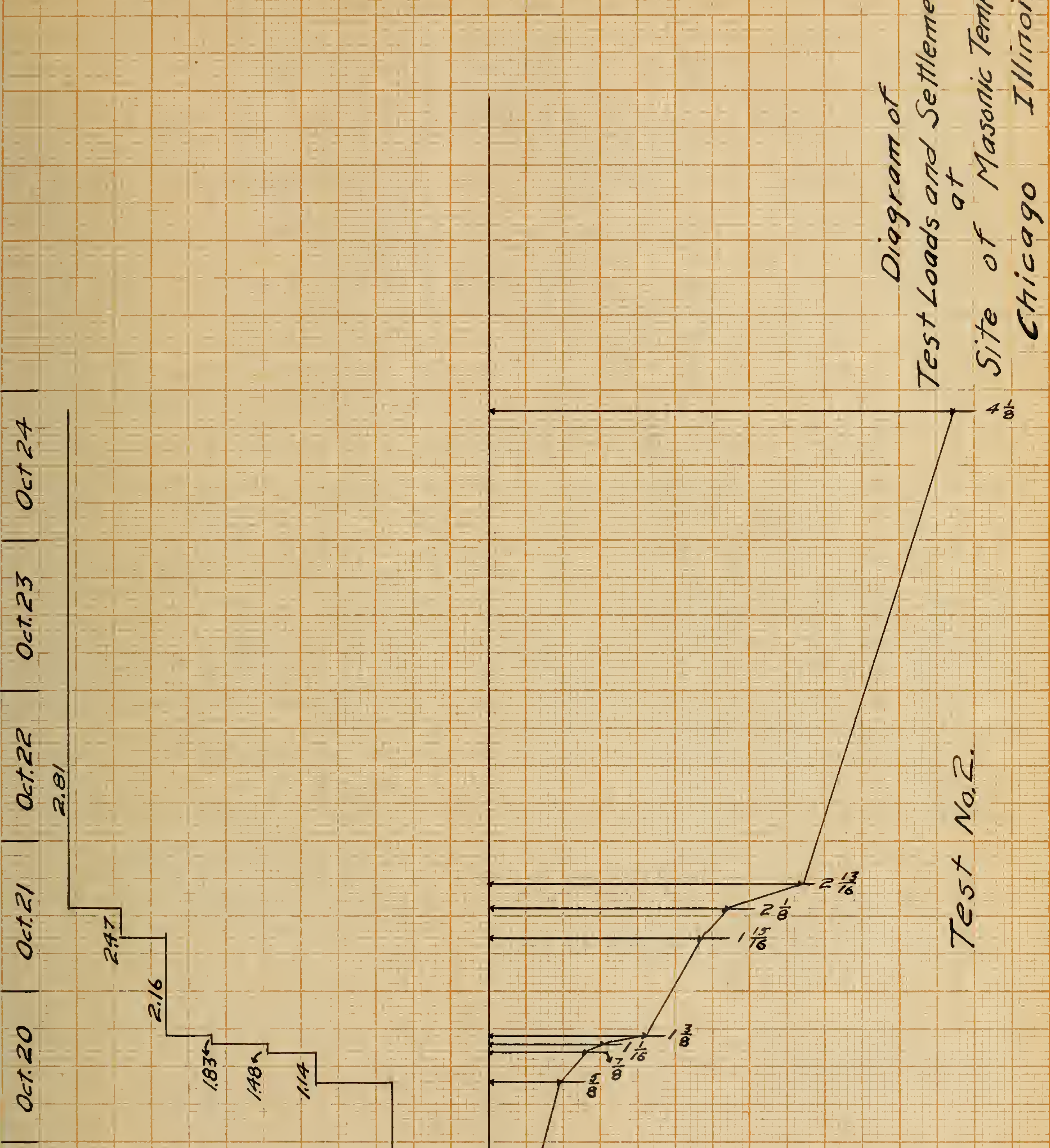
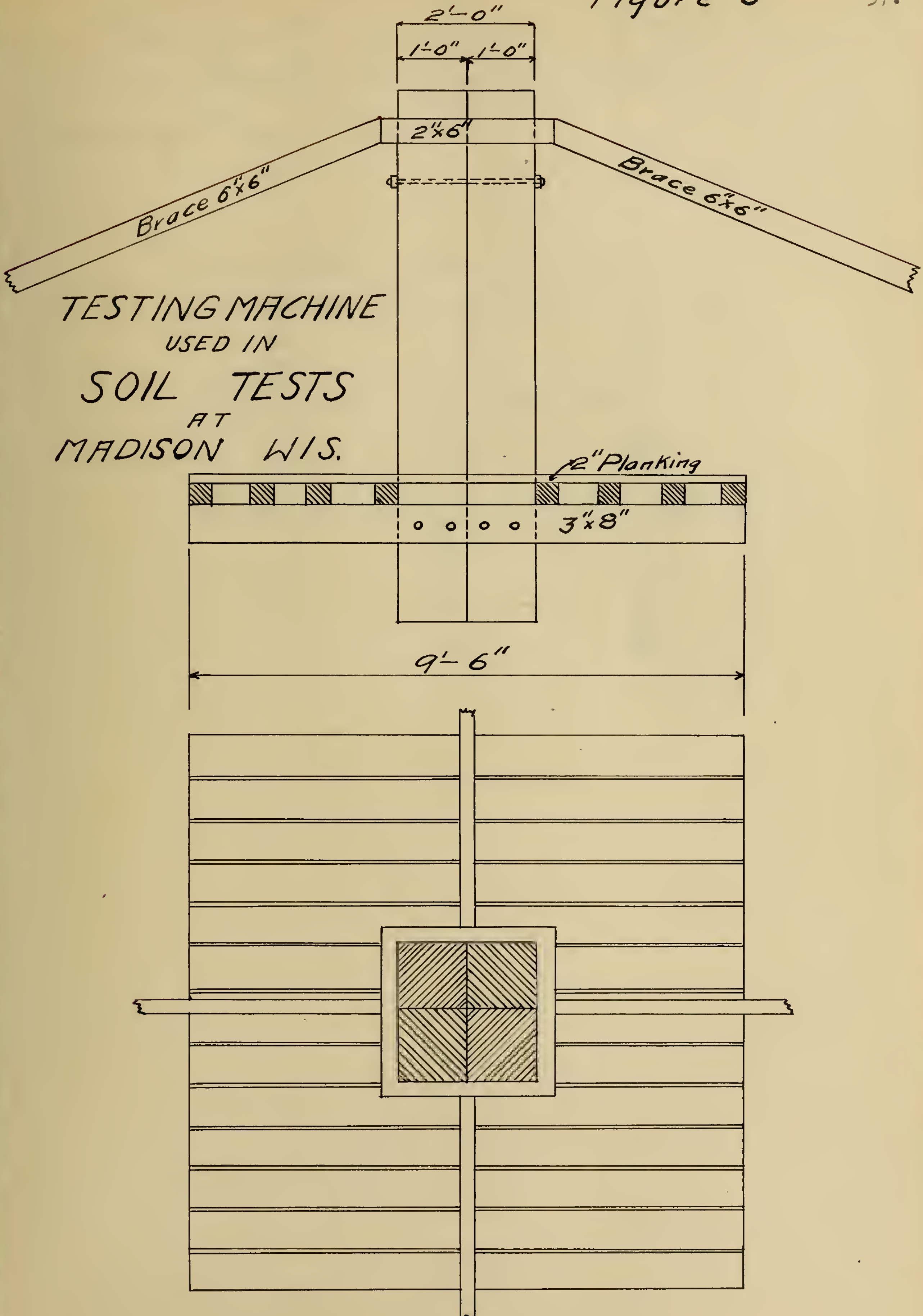


Diagram of
Test Loads and Settlements
at
Site of Masonic Temple
Chicago Illinois
Test No. 2.
Oct. 18
Oct. 19
Oct. 20
Oct. 21
Oct. 22
Oct. 23
Oct 24
Load in Tons per sq. ft.
Settlement in inches
.016
.66
1.14
1.48
1.83
2.16
2.47
2.81
5/8
7/8
1 1/16
1 3/8
1 15/16
2 1/8
2 13/16
4 1/8
3
2
1
0
1
2
3
4

(7) CAPITOL BUILDING, MADISON, WISCONSIN.

The State Capitol at Madison, Wisconsin, is founded on glacial drift, 16 feet below the surface. The drift is composed of fine compact sand and small pebbles. The footings for the dome foundations were designed to impose a load of 4 tons per sq. ft. on the drift, and tests were made to see if this was within the bearing capacity of the soil. The tests were made as follows:- The soil was excavated to subgrade, care being taken not to disturb the bottom of the pit which was accurately trimmed with a straight-edge. A mast, built up of 4 timbers, one ft. square, was rested on this surface, and the load was placed on a platform bolted to this mast. The mast was plumbed and maintained in a vertical position by means of braces. The platform was loaded with sacks of cement, so placed that the load was balanced, until the total load reached 7 tons per sq. ft. at which point the platform broke. Fig. 6 shows the apparatus used in this test. No upheaval was observed and the soil remained perfectly dry during the test. Settlements were read to 1/64 of an inch. The results of this test are given in Table 10 and in Diagram 12.

Figure 6



TESTING MACHINE USED IN SOIL TESTS AT MADISON WIS.

Table 10

Soil Test at Site of Capitol B'ld'g, Madison, Wis.

Material Tested:- Fine Compact Sand

Bearing Area:- 4 Sq. Ft.

No. of Days Load Remained	Load in Tons per sq. ft.	Settlement in inches
$\frac{1}{2}$	$\frac{3}{4}$	$\frac{2}{64}$
$\frac{1}{2}$	$1\frac{5}{8}$	$\frac{4}{64}$
Remained 2	da. No further	Settlement
$\frac{1}{2}$	$2\frac{1}{2}$	$\frac{6}{64}$
$\frac{1}{2}$	$3\frac{1}{2}$	$\frac{8}{64}$
Remained 7	da. No further	Settlement
1	$4\frac{1}{4}$	$\frac{9}{64}$
$\frac{1}{2}$	5	$\frac{10}{64}$
$\frac{1}{2}$	6	$\frac{11}{64}$
1	7	$\frac{12}{64}$

Diagram 12

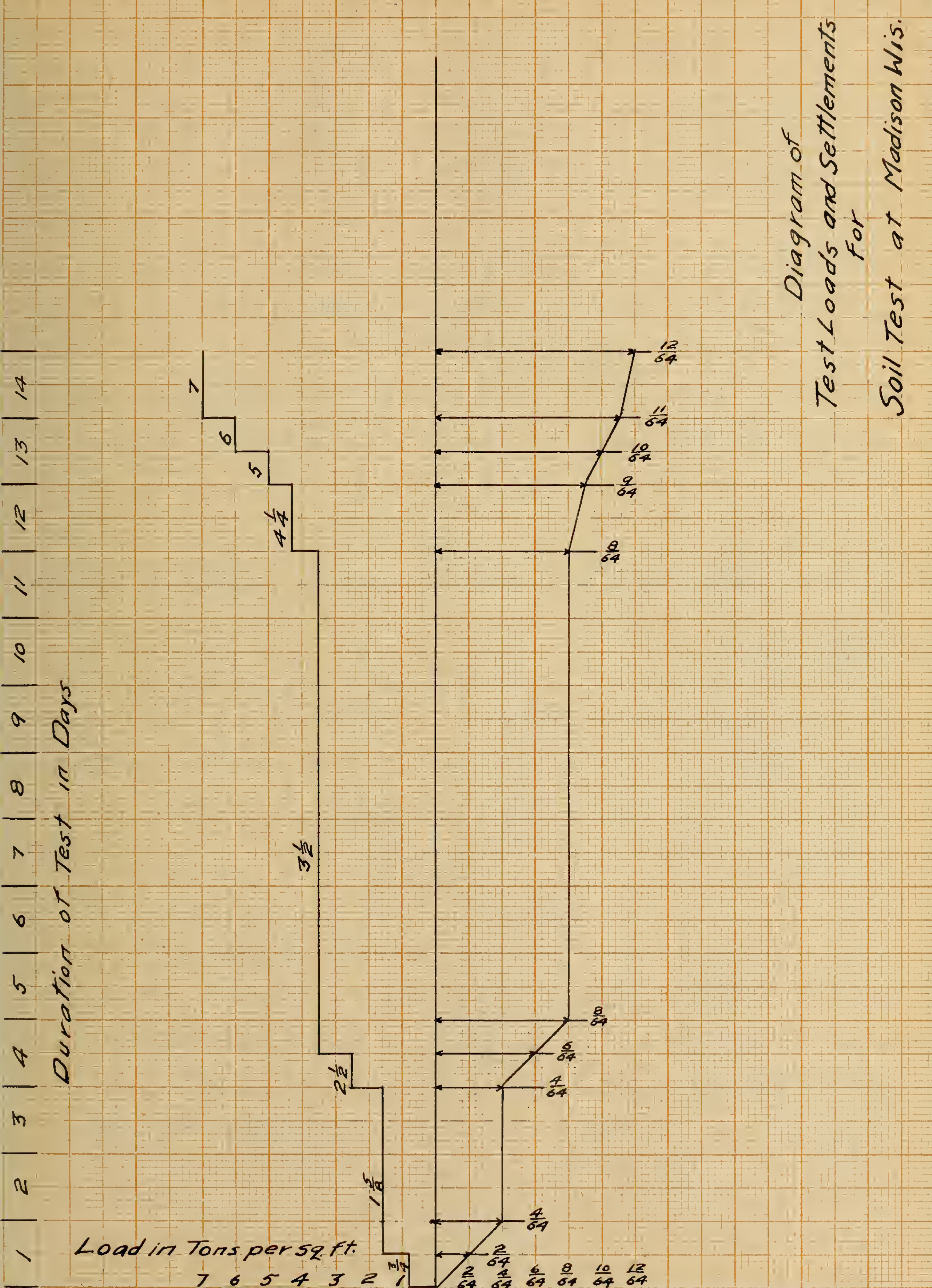
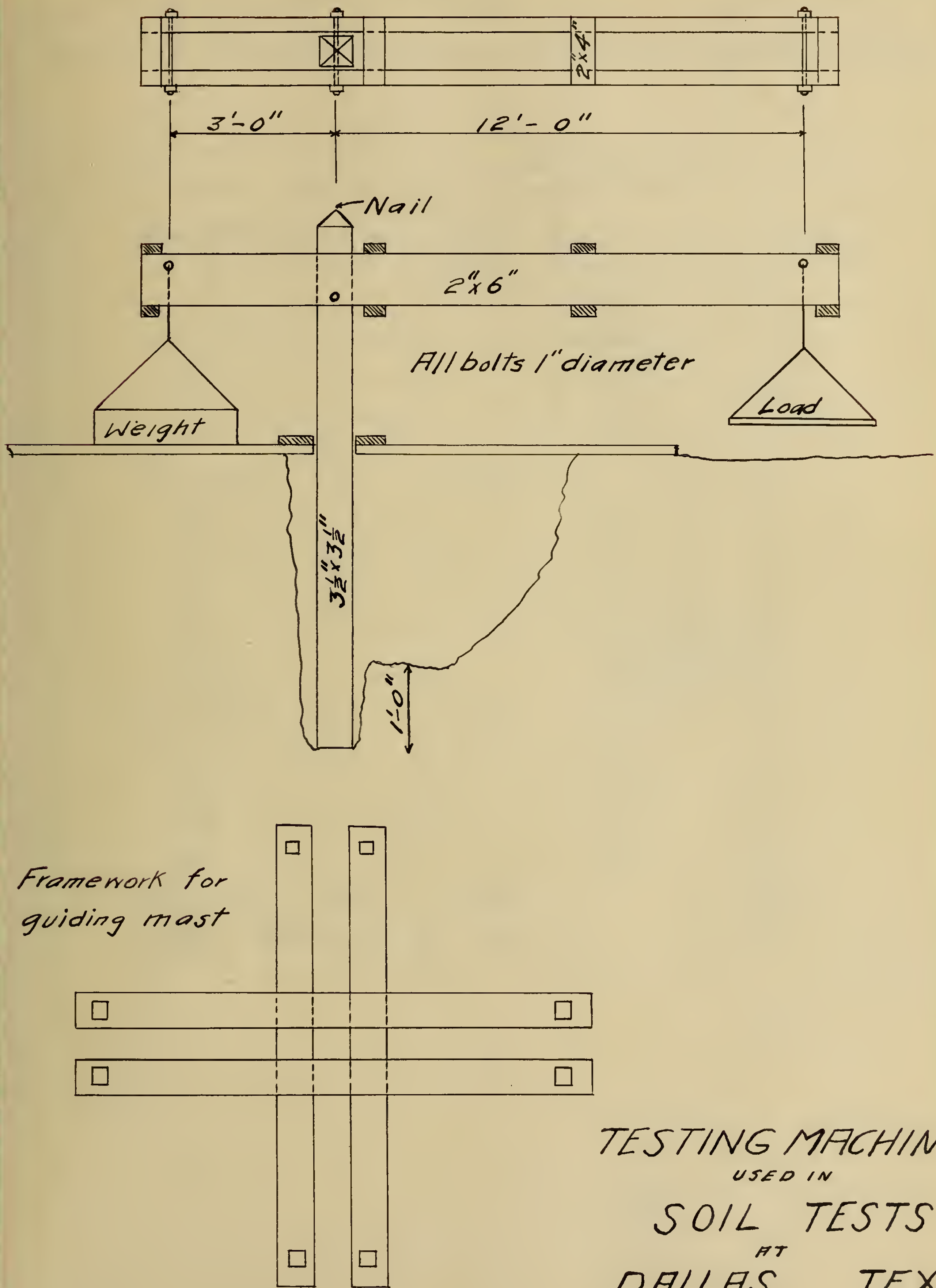


Diagram of
Test Loads and Settlements
for
Soil Test at Madison Wis.
Duration of Test in Days
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Load in Tons per sq. ft.
7 6 5 4 3 2 1
3/4
1 5/8
2 1/2
3 1/2
4 1/4
5
6
7
2/64 4/64 6/64 8/64 10/64 12/64
2/64
4/64
4/64
6/64
8/64
8/64
9/64
10/64
11/64
12/64
U. OF I. S. S. FORM 3

(8) THE DALLAS-OAK PARK VIADUCT, DALLAS, TEXAS.

The Dallas-Oak Park viaduct spans the Trinity River between the cities of Dallas and Oak Park, Texas. The foundations as originally designed were to consist of concrete piles, each of which should support 50 tons for 48 hours without any settlement and should show a settlement of only 1/4 inch after supporting a load of 60 tons for 48 hours. The contractors found it impossible to fulfill these conditions, and the design of the footings was changed so that the maximum load per pile was 20 tons with a soil pressure of 16 tons per sq. ft. A maximum pressure of 2.9 tons per sq. ft. could occur on the soil if the piles took no load whatever. The soil is a hard, compact, black or yellow clay, underlaid by sand and gravel. Tests were made to determine the bearing capacity of this soil. Pits 6 to 8 ft. deep were dug, and the soil tested by applying a load to a mast 5 1/2 inches square. The foot of this mast rested in a hole 4 inches square and one foot below the average level of the bottom of the pit. This was expected to eliminate upheaval around the edges of the mast. At the time of making the tests, the soil was very dry, and water was poured into the pit and allowed to stand during the tests. The loads were applied to the mast by means of a lever, and dirt was used as the loading material. The construction and method of using this apparatus is shown in Fig. 7 . Several tests were made giving fairly uniform results, and the results of a typical test are given in Table 11 and in Diagram 15 . Other tests made with a mast one foot square gave practically the same results. The apparatus used in this test was designed and operated by Mr. W. L. Dunn, a former Illinois student.

Figure 7.



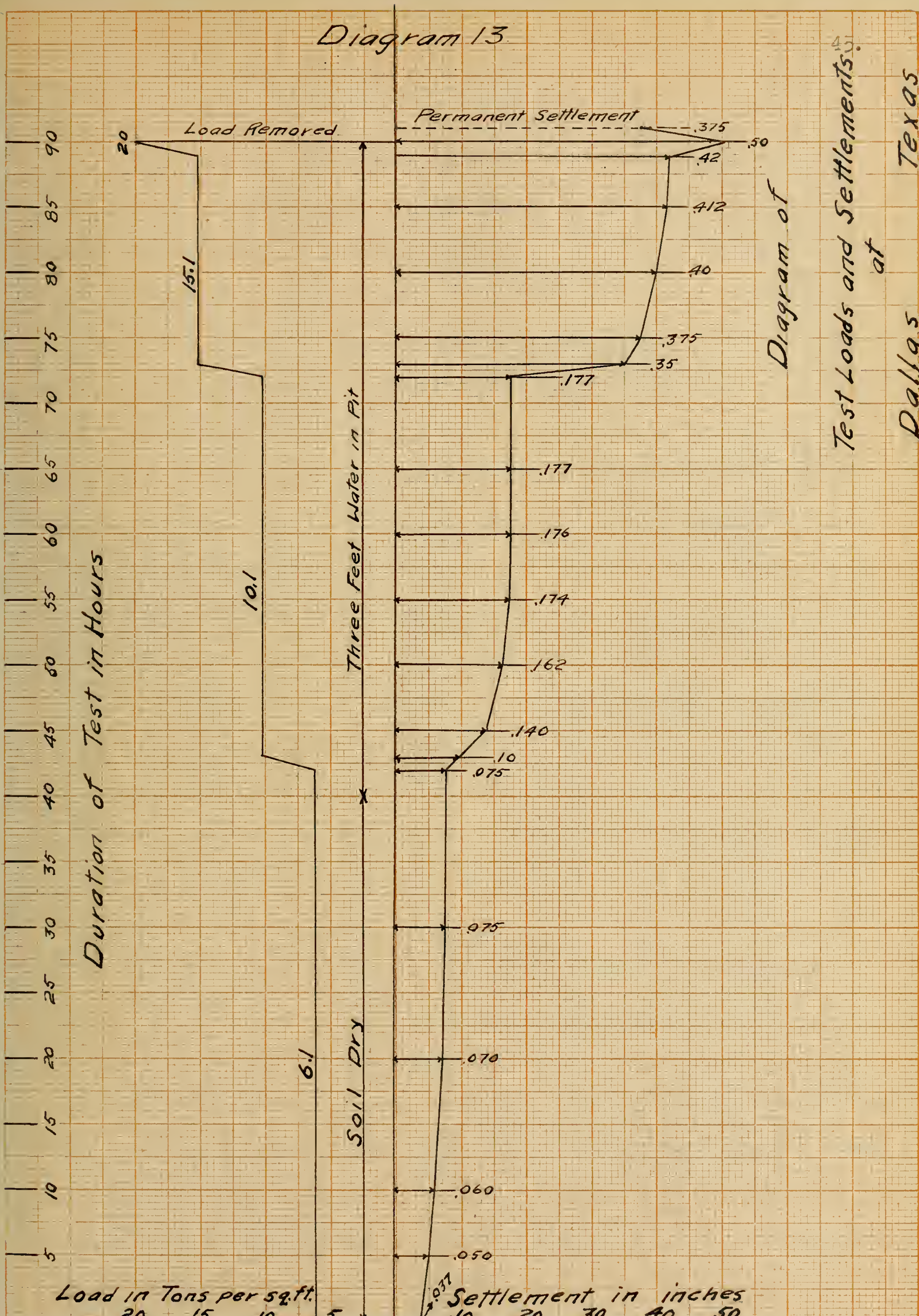
TESTING MACHINE
USED IN
SOIL TESTS
AT
DALLAS TEX.

Table 11.

Soil Test at Site of County Bridge, Dallas, Texas

Material Tested:- Compact Clay. Bearing Area:- $12\frac{1}{4}$ sq. in.

Duration of Test in Hours	Load in Tons per sq. ft.	Settlement Immediate	Settlement Additional	Settlement Total
0	6.1	.037	—	.037
5	"	—	.013	.050
10	"	—	.010	.060
20	"	—	.010	.070
30	"	—	.005	.075
42	"	—	.000	.075
42 to 43	10.1	.025	—	.100
45	"	—	.040	.140
50	"	—	.022	.162
55	"	—	.012	.174
60	"	—	.002	.176
65	"	—	.001	.177
72	"	—	.000	.177
72 to 73	15.1	.173	—	.350
75	"	—	.025	.375
80	"	—	.025	.400
85	"	—	.012	.412
89	"	—	.008	.420
89 to 90	20.0	.080	—	.500
Load Removed at 90				.375



U. OF I. E. S. FORM 3

(9) STATE CAPITOL, ALBANY, NEW YORK.

The design of the foundations of the State Capitol at Albany, New York, was intrusted to Mr. W. J. McAlpine. Test pits and borings showed that the surface soil was composed of a strata of blue clay and sand, varying in thickness from 1 to 35 feet. Underlying this was a strata of blue clay, 100 feet or more in thickness. The blue clay contained from 60 to 90 percent of alumina, the remainder being silicious sand. The percent of moisture varied greatly, ranging from 27 to 45 percent. Two sets of experiments were made to determine the bearing capacity of this clay. In the first experiment, the apparatus used was a mast 12 inches square held perpendicular by guys, with a cross-frame for weights. A pit 18 inches square at the top, 14 inches square at the bottom, and 5 feet deep was dug, and the foot of the mast was rested in this pit. Weights were then applied to the platform and the corresponding settlements noted. In order to detect any upheaval, small stakes were driven into the ground in radial lines from the center of the mast, and the tops were carefully leveled. The upheaval could then be measured by means of a straight edge. The results of this test are given in Table 12 and in Diagram 14.

A second test was made by fastening a frame 5 feet square to the foot of the mast, and resting this on the bottom of a pit, 58 inches square at the top and bottom and 5 feet deep. The platform was then loaded and the settlements noted. The upheaval was measured in the same manner as in the previous test. The results of this test are given in Table 13 and in Diagram 15. From the results of these tests, Mr. McAlpine assumed the maximum supporting power of the soil to be 6 tons

per sq. ft. and the safe working pressure to be 2 tons per sq. ft. The building was constructed under this assumption and the foundations have failed partially and bad cracks have appeared in the building.

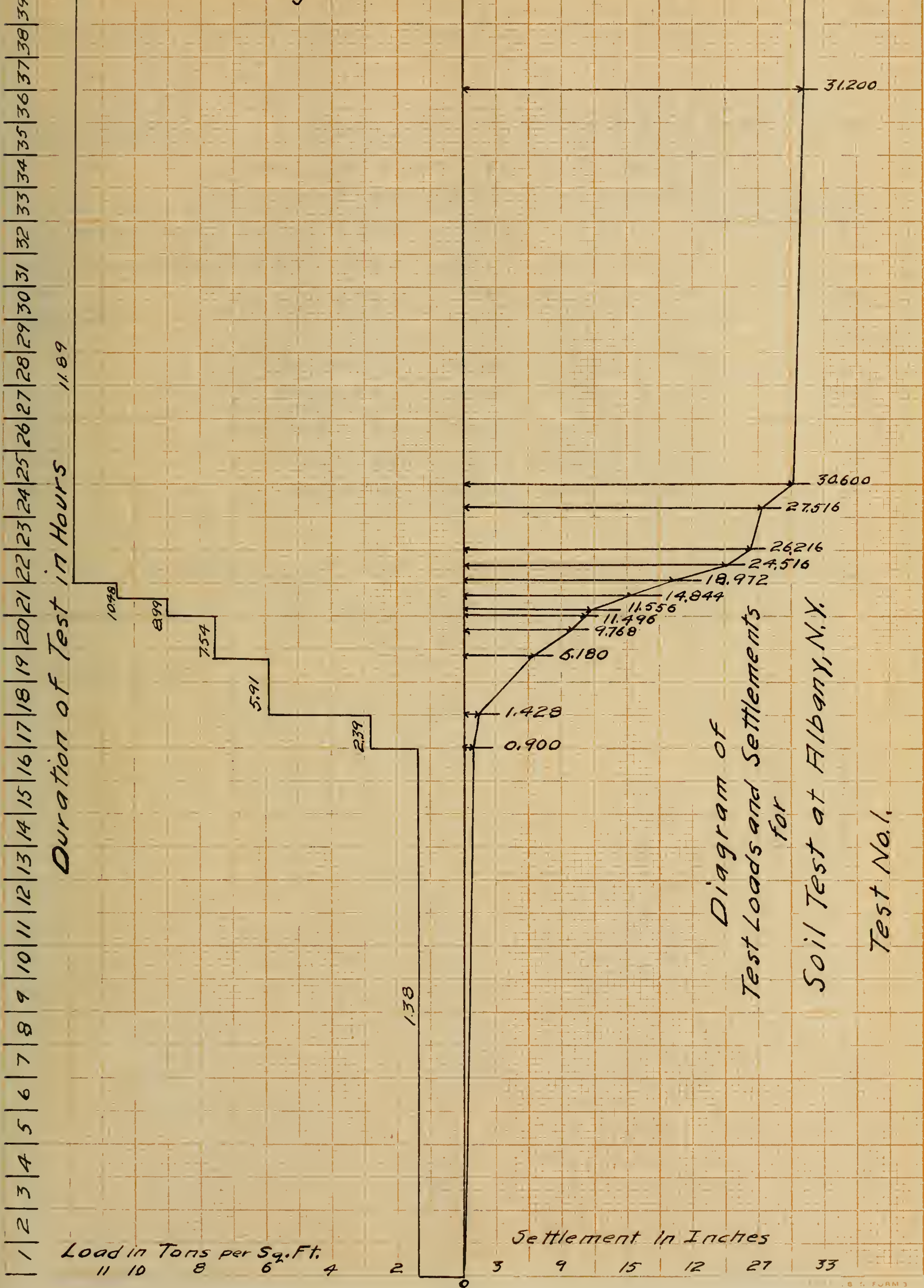
Table 12

SOIL TESTS AT SITE OF STATE CAPITOL, ALBANY, NEW YORK.

Test No. 1. Soil Tested:- Blue Clay Area Tested:- 1 sq. ft.

Day	Duration Hours	Weights		Settlements		Remarks
		Each Pounds	Total Pounds	Each Inches	Total Inches	
Mon., 5, P.M.		2754	2754	0.288	0.288	Weight of Machine
" 9, A.M.	16			0.612	0.900	
" 9, "		2820	5574			1st Stone Added
" 10, "	1			0.528	1.428	
" 10, "		6260	11834			2nd & 3rd Stone Added
" $11\frac{3}{4}$, "	$1\frac{3}{4}$			4.752	6.180	Uplift Noted
" $11\frac{3}{4}$, "		3250	15084			4th Stone Added
" $\frac{1}{2}$, P.M.	$\frac{3}{4}$			3.588	9.768	
" 1, "	$\frac{1}{2}$			1.728	11.496	
" 1, "	5 min.	2890	17974	0.060	11.556	5th Stone Added
" $1\frac{1}{2}$, "	$\frac{1}{2}$			3.288	14.844	Immediate Settlement
" $1\frac{1}{2}$ "		2980	20954			6th Stone Added
" 2, "	$\frac{1}{2}$			4.128	18.972	Uplift Noted
" 2, "		2830	23784			7th Stone Added
" $2\frac{1}{2}$, "	$\frac{1}{2}$			5.184	24.156	
" 3, "	$\frac{1}{2}$			2.060	26.216	
" $4\frac{1}{3}$, "	$1\frac{1}{3}$			1.300	27.516	
" 5, "	$\frac{2}{3}$			3.084	30.600	Uplift Noted
Wed. 5, A.M.	12			0.600	31.200	
" 8, "	3				31.200	No Settlement after
						5 A.M.

Diagram 14.



Duration of Test in Hours
Load in Tons per Sq. Ft.
Settlement In Inches
Diagram of Test Loads and Settlements for Soil Test at Albany, N.Y.
Test No. 1.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
11 10 8 6 4 2
0
3 9 15 12 27 33
1.38
2.39
5.91
7.54
8.99
10.48
11.89
0.900
1.428
6.180
9.768
11.496
11.556
14.844
18.972
24.516
26.216
27.516
30.600
31.200
31.200

Table 13.

Test No. 2 Soil Tested:- Blue Clay Area Tested:- 1 sq. yd.

Observation	Weights			Settlements		Remarks
	Each Pounds	Total Pounds	Per Sq. Foot	Each Inches	Total Inches	
Machine Placed	3228	3228	359			No settlement
1st Stone Added	2380	5608	623	0.050	0.050	
2nd " "	3300	8908	990	0.150	0.200	Estimated
3rd & 4th " "	6960	15868	1763	0.166	0.366	
5th " "	2830	18698	2078	0.134	0.500	"
6th " "	3250	21948	2439	0.124	0.624	
7th " "	4420	26368	2929	0.096	0.720	"
8th " "	1190	27558	3062	0.080	0.800	
9th " "	2320	29878	3320	0.025	0.825	

The notations of the settlements were generally made about an hour after the weights were applied.

Diagram 15

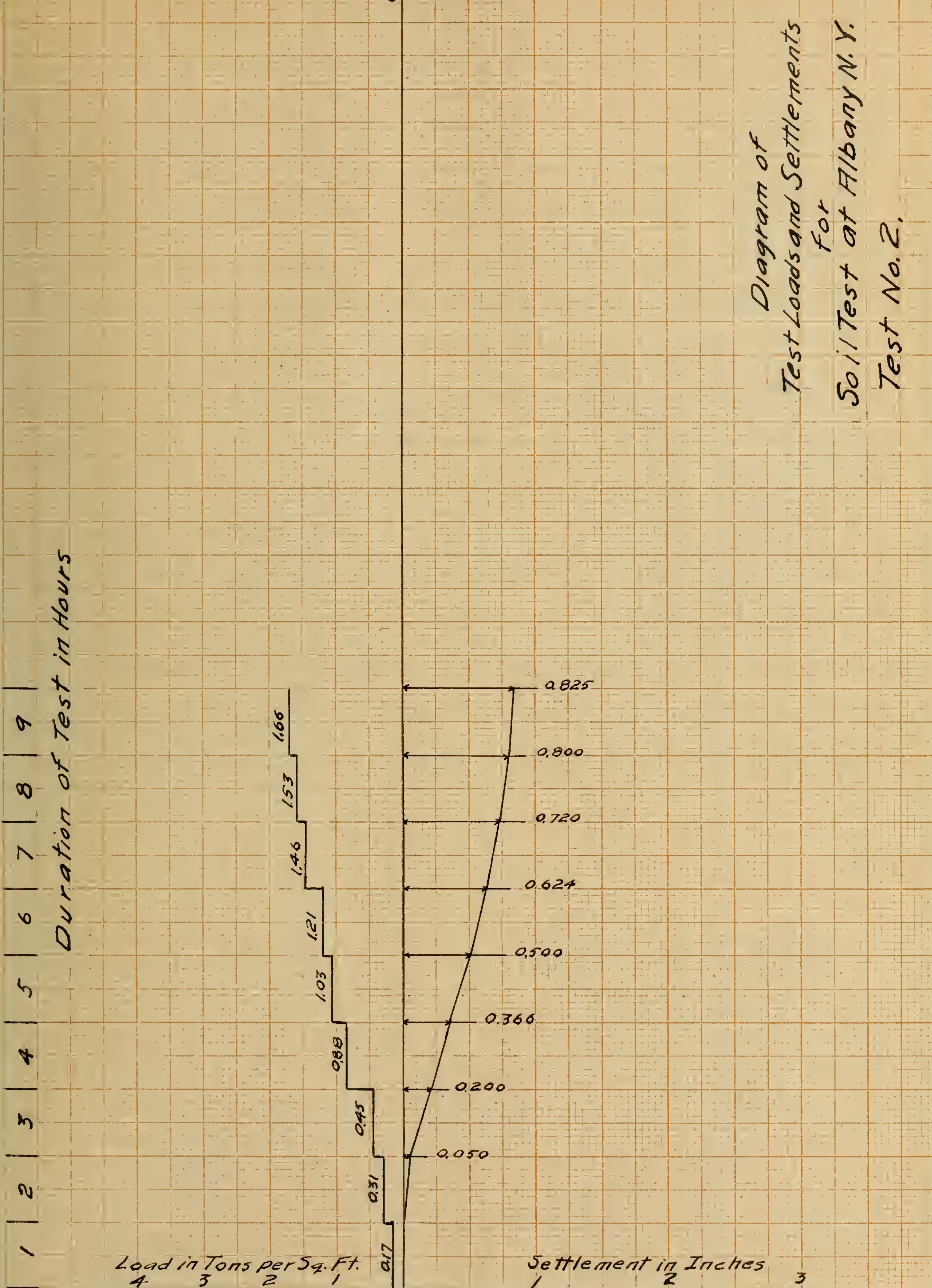


Diagram of
Test Loads and Settlements
for
Soil Test at Albany N. Y.
Test No. 2.
Duration of Test in Hours
1
2
3
4
5
6
7
8
9
Load in Tons per Sq. Ft.
4
3
2
1
0
Settlement in Inches
1
2
3
0.17
0.31
0.45
0.88
1.03
1.21
1.46
1.53
1.66
0.050
0.200
0.366
0.500
0.624
0.720
0.800
0.825

(10) NEW ORLEANS, LOUISIANA.

Tests of the bearing capacity of the soil at New Orleans, Louisiana, were made by Mr. J. F. Llewellyn for the purpose of obtaining the allowable pressure on the foundation of an elevated water tank. Three pits were dug, each 5 feet deep and 4 feet square, and a platform 5 feet square was placed in the bottom of each pit. These platforms were loaded with scrap-iron until the load was above the water line which was 18 inches below the surface. Bricks were used as the loading material after the water line had been passed. The platforms were loaded until the load on the first reached 650 pounds per sq. ft, that on the second 1000 pounds per sq. ft., and that on the third 1500 pounds per sq. ft. These loads were allowed to remain on the soil for a number of days, and the settlements were noted to the 1/32 of an inch. According to the results of these tests, 650 pounds per sq. ft. was assumed as the safe working pressure and the tower was constructed under this assumption. The results of these tests are given in Table 14 and in Diagram16.

Soil Test at New Orleans La.

Material Tested:- Loam Bearing Area:- 9 Sq. Ft.

Table 14.

Date	Load in lb per sq. ft.	Settlement in inches
Pit No. 1		
Dec. 13		
to Dec. 17	650	$\frac{1}{8}$
" 19	650	$\frac{1}{8}$
" 24	650	$\frac{5}{32}$
Pit No. 2		
Dec. 13		
to Dec. 17	1000	$\frac{5}{16}$
" 19	1000	$\frac{6}{16}$
" 24	1000	$\frac{1}{2}$
Pit No. 3		
Dec. 13		
to Dec. 14	1300	$\frac{3}{8}$
" 19	1300	$\frac{7}{16}$
" 24	1300	$\frac{1}{2}$

Date	Weather
Dec. 13	Clear & Cold
" 14	"
" 15	Cloudy & Damp
" 16	"
" 17	"
" 18	Rained
" 19	Cloudy
" 20	Clear & Warm
" 21	"
" 22	"
" 23	Cloudy
" 24	Rained

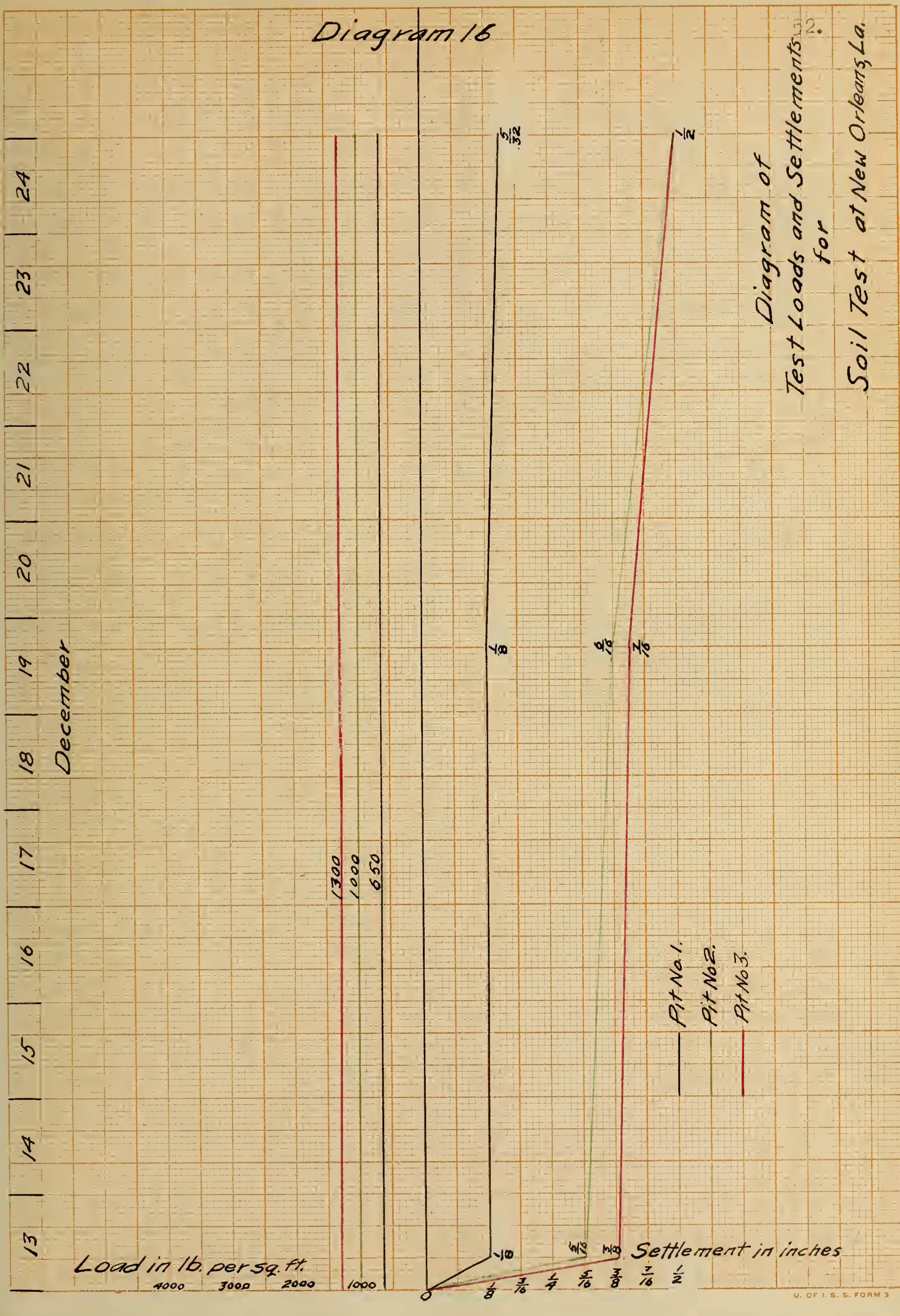


Diagram 16
Diagram of
Test Loads and Settlements
for
Soil Test at New Orleans, La.
December
13
14
15
16
17
18
19
20
21
22
23
24
1300
1000
650
Pit No. 1.
Pit No. 2.
Pit No. 3.
Load in lb. per sq. ft.
4000
3000
2000
1000
0
Settlement in inches
1/8
3/16
1/4
5/16
3/8
7/16
1/2
5/32
6/16
7/16
U. OF I. S. S. FORM 3

(11) NEW ORLEANS, LOUISIANA.-BY MR. JOHN ROY.

New Orleans is probably one of the most difficult places in the United States in which to construct a reliable foundation. The surface soil is composed of silt deposited by the Mississippi River and is of such great depth that foundations cannot be extended to rock. The United States Army Engineers who had charge of the construction of important structures in that vicinity, experienced great difficulty in building satisfactory foundations, and in 1851, Mr. John Roy who superintended the construction of the United States Custom House at New Orleans was instructed to make a series of tests on the bearing capacity of the Mississippi River silt. The tests extended over a period of two years and are the most complete tests of which there is any record. No data as to the manner in which these tests were made can be obtained, but the results are shown in Table 15 and in Diagrams 17 to 21.

Table 15.

TESTS OF COMPRESSIBLE SOILS AT NEW ORLEANS, LA.

No. Bearings	Size of Bearing Inches	Area Br'g. Sq. In.	Weight Applied Pounds	Weight Pounds Sq. In.	Settlement Inches	Duration Days	Depth of Test Inches
1	$\frac{1}{4} \times \frac{1}{4}$	$\frac{1}{16}$	6.375	102.0	$3\frac{1}{2}$	30	12
1	$\frac{1}{2} \times \frac{1}{2}$	$\frac{1}{4}$	25.50	102.0	7	30	12
1	$\frac{3}{4} \times \frac{3}{4}$	$\frac{9}{16}$	57.375	102.0	11	30	12
1	1 x 1	1	102.0	102.0	11	30	12
1	$1 \times 2\frac{7}{8}$	$2\frac{7}{8}$	293.25	102.0	$26\frac{3}{4}$	30	12
1	4x4	16	1632.0	102.0	78	30	12
1	1x16	16	1632.0	102.0	33	30	12
1	4x4	16	1632.0	102.0	120	161	48
1	$\frac{1}{4} \times \frac{1}{4}$	$\frac{1}{16}$	1.125	18.0	$\frac{3}{8}$	3	12
1	$\frac{1}{4} \times 1$	$\frac{1}{4}$	4.50	18.0	$\frac{5}{8}$	3	12
1	$\frac{1}{2} \times 1$	$\frac{1}{2}$	9.00	18.0	$\frac{5}{8}$	3	12
1	$\frac{3}{4} \times 1$	$\frac{3}{4}$	13.50	18.0	$\frac{5}{8}$	3	12
1	1x1	1	18.00	18.0	$\frac{5}{8}$	3	12
1	1x1	1	36.00	36.0	$2\frac{1}{2}$	51	12
1	$\frac{3}{4} \times 1$	$\frac{3}{4}$	27.00	36.0	$1\frac{3}{4}$	51	12
1	$\frac{1}{2} \times 1$	$\frac{1}{2}$	18.00	36.0	$1\frac{1}{4}$	51	12
2	$2\frac{1}{2} \times 8$	40	642.0	16.05	$\frac{7}{8}$	99	6
4	1x1	4	170.0	42.50	$\frac{1}{8}$	42	0
2	6x12	144	2552.0	17.72	$\frac{1}{8}$	107	0
2	6x12	144	3362.0	23.35	$\frac{3}{16}$	182	0
2	6x24	288	15580.0	54.097	1	48	0
1	$20\frac{7}{8} \times 20\frac{7}{8}$	432	18703.0	43.30	$4\frac{1}{2}$	26	96
1	12x12	144	5132.0	35.64	$\frac{3}{4}$	20	96
1	24x24	576	23150.0	40.20	$6\frac{1}{4}$	38	36
1	"	"	45724.0	79.38	$13\frac{1}{4}$	40	36
1	"	"	57600.0	100.00	$18\frac{1}{2}$	55	36
1	1 x 1	1	102.0	102.0	6	68	48
1	"	1	202.0	202.0	18	121	48

Table 15, Cont.

No Bearings	Size Bearing Inches	Area B'r'g Sq. In.	Weight Applied Pounds	Weight Pounds Sq. In.	Settlement Inches	Duration Days	Depth of Test Inches
1	4x4	16	1632.0	102.0	16 $\frac{1}{2}$	68	48
1	"	"	3232.0	202.0	54 $\frac{1}{2}$	121	48
1	1x1	1	102.0	102.0	1	49	48
1	"	1	202.0	202.0	7	87	48
1	4x4	16	1632.0	102.0	7	51	48
1	"	"	3232.0	202.0	61 $\frac{1}{2}$	87	48

Diagram 17.

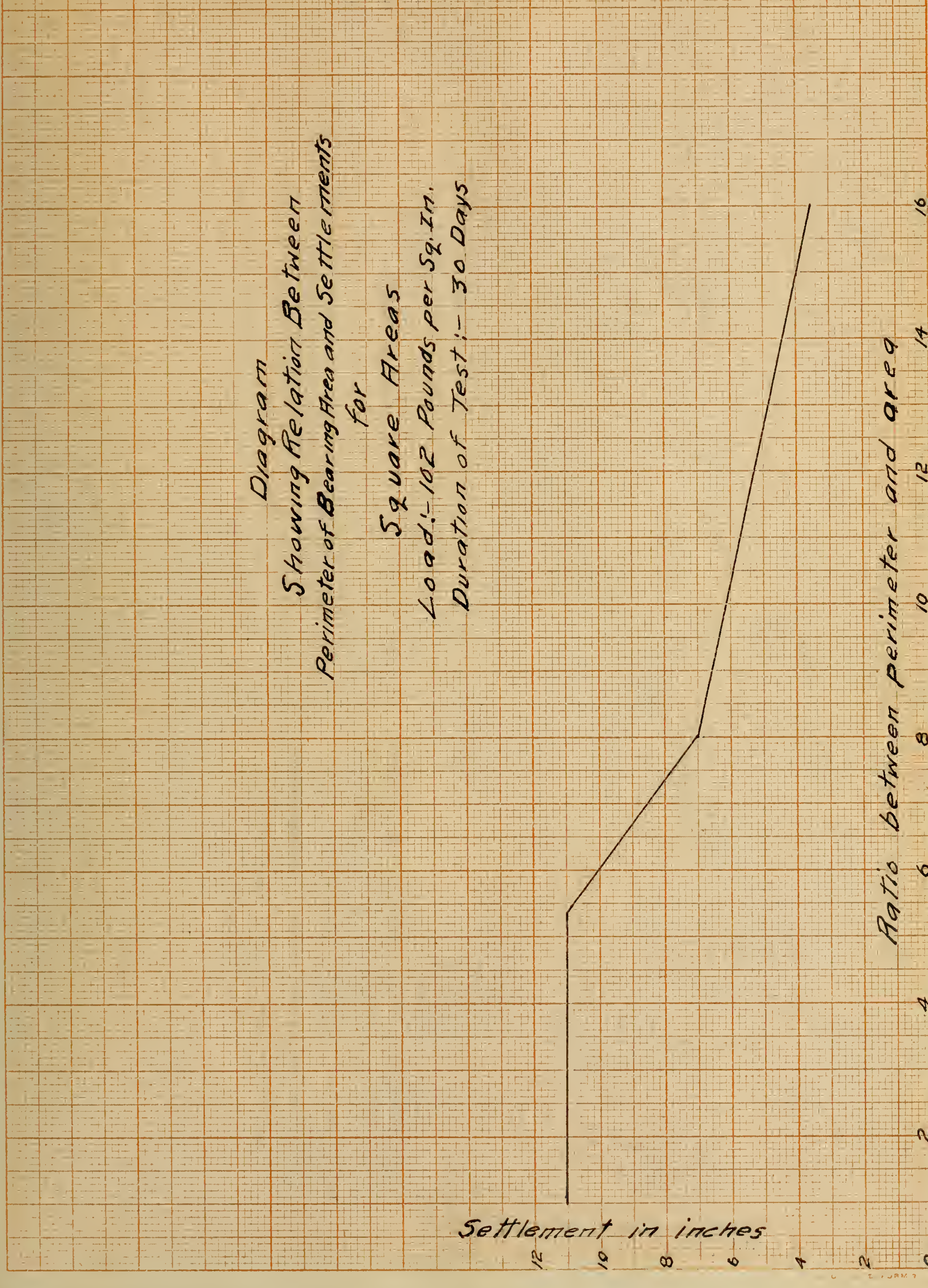


Diagram
Showing Relation Between
Perimeter of Bearing Area and Settlements
for
Square Areas
Load:- 102 Pounds per Sq. In.
Duration of Test:- 30 Days
Ratio between perimeter and area
0
2
4
6
8
10
12
14
16
Settlement in inches
12
10
8
6
4
2
0

Diagram 18.

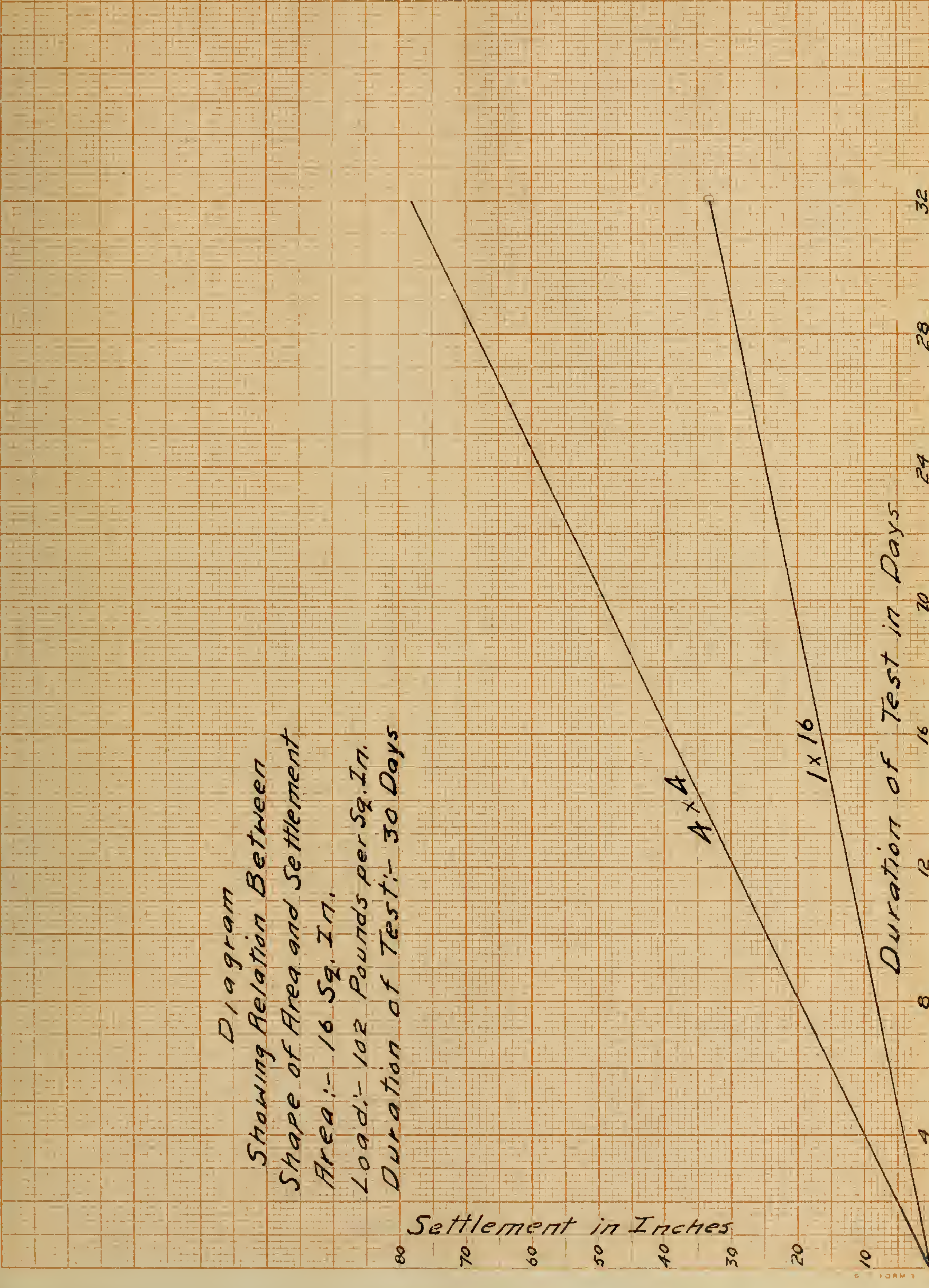


Diagram
Showing Relation Between
Shape of Area and Settlement
Area:- 16 Sq. In.
Load:- 102 Pounds per Sq. In.
Duration of Test:- 30 Days
4 x 4
1 x 16
Settlement in Inches
80
70
60
50
40
30
20
10
Duration of Test in Days
4
8
12
16
20
24
28
32

Diagram 19.

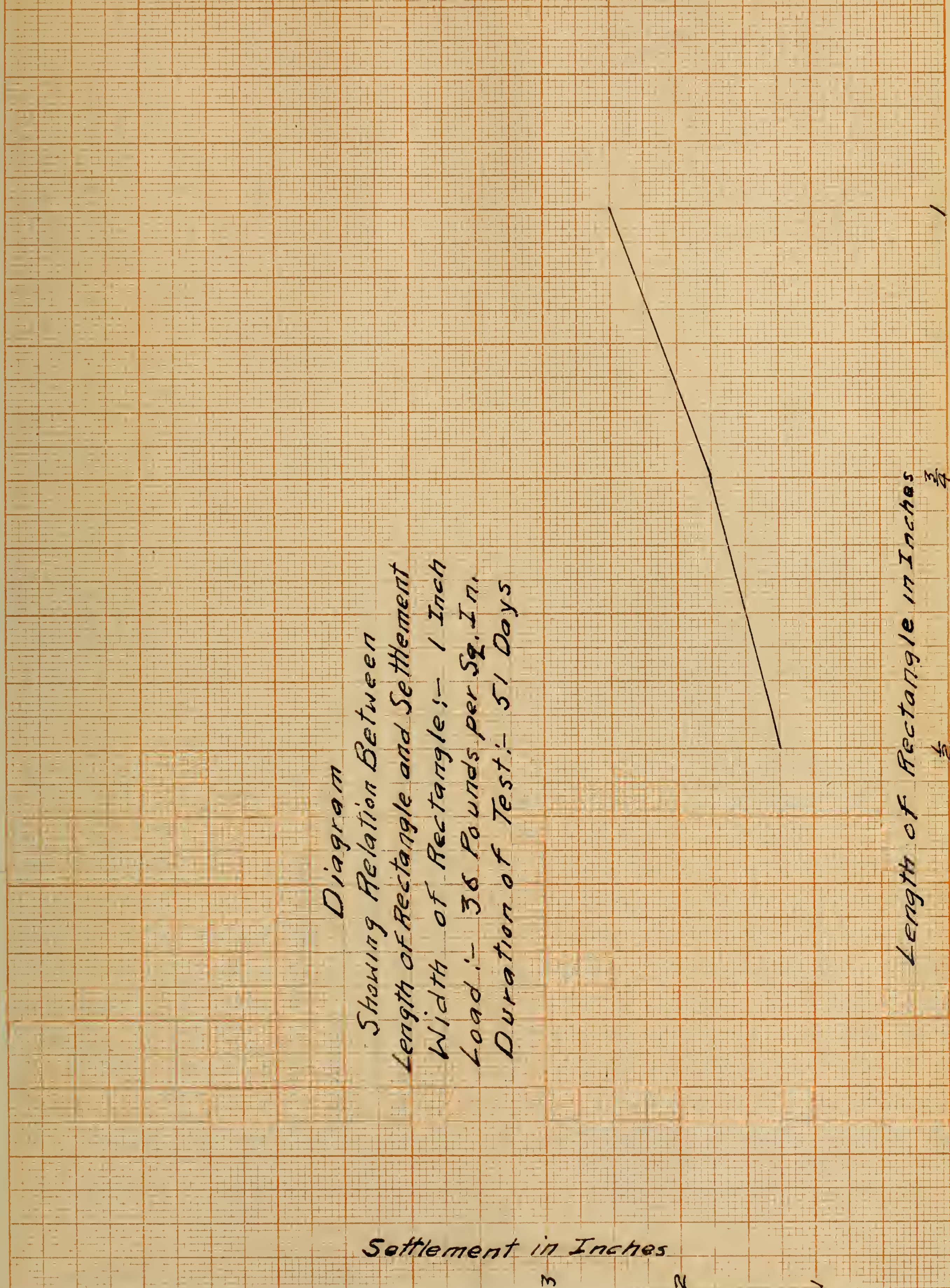


Diagram
Showing Relation Between
Length of Rectangle and Settlement
Width of Rectangle:– 1 Inch
Load:– 36 Pounds per Sq. In.
Duration of Test:– 51 Days
Length of Rectangle in Inches
1
3/4
1/2
Settlement in Inches
3
2
1

Diagram 20.

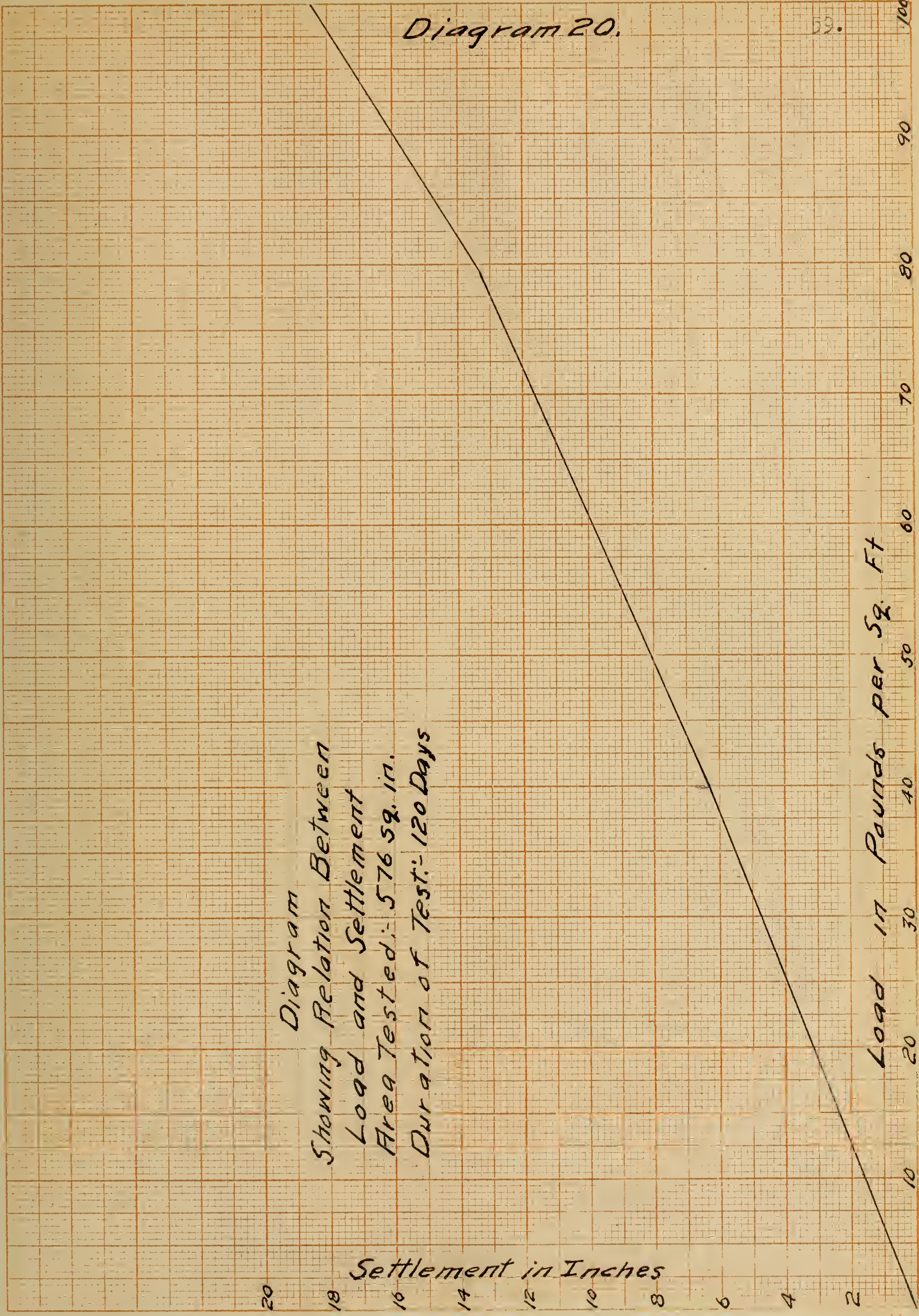


Diagram
Showing Relation Between
Load and Settlement
Area Tested:- 576 sq. in.
Duration of Test:- 120 Days
Load in Pounds per Sq. Ft
10
20
30
40
50
60
70
80
90
100
Settlement in Inches
2
4
6
8
10
12
14
16
18
20

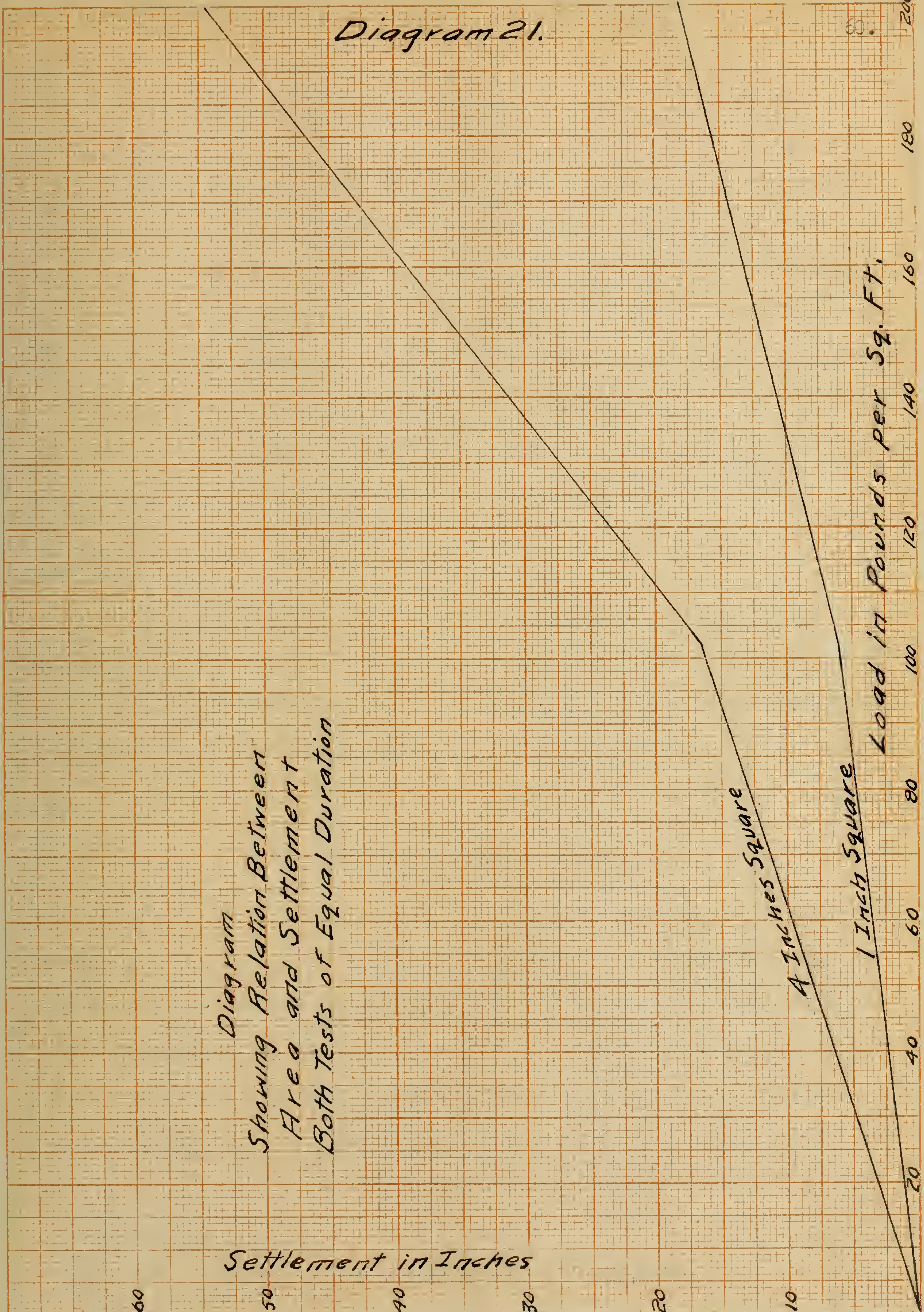


Diagram 21.
69.
Diagram
Showing Relation Between
Area and Settlement
Both Tests of Equal Duration
4 Inches Square
1 Inch Square
Load in Pounds per Sq. Ft.
Settlement in Inches
200
180
160
140
120
100
80
60
40
20
60
50
40
30
20
10

(12) TYREE DOCKS.

The first test of which there is any record was conducted at the proposed site of the Tyree Docks in England. The soil was a very soft and plastic loam, and some value of its bearing power had to be obtained before even a tentative design could be made. A concrete platform, ten feet square, was built and gradually loaded with pig iron. No settlement was observed until the load reached 700 pounds per square foot, but after this the settlement was constant. The docks were built with a pressure of 500 pounds per square foot, and no settlement has been observed.

(13) BARRY DOCKS.

The foundation of Barry Docks, in England, are laid upon a strata of very soft and plastic clay. Tests showed that no settlement would occur until the load reached two tons per square foot, but after this the settlement was constant and very similar to the sinking of a weight in a viscous fluid. No description of the testing apparatus could be obtained.

(14). HOSPITAL AT BERCKE, FRANCE.

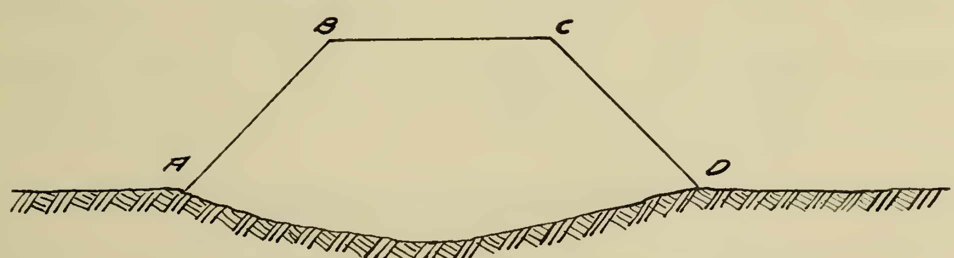
The hospital at Bercke, France, is built on the beach, and in the design it was planned to lay the foundation on the original contours of the sand. Later it was decided to level up the site, and tests on loose sandwere made by placing it in a box, 3 feet deep and 3 feet square, and ramming it. This compressed th sand 2 3/4 to 3 1/2 inches, and when water was added, it settled 2 inches more. A pile, 4 inches square, would penetrate only 3 inches, and when loaded further, it would raise the sand around the base.

The foundation site was prepared by ramming the sand. No value,

as to the pressure used, could be obtained.

(15). WESTERN RAILWAY OF FRANCE.

In the construction of the Western Railway of France, an embankment was to be built across very swampy ground. The soil was a very soft loam, and tests of its bearing capacity were made by building masonry piers, 6.56 feet square, and by loading them to twice the weight of the embankment. The piers showed no settlement but the completed embankment settled very badly. The only explanation that can be offered for this is that the shear along the perimeter of the pier helped to support it. The masonry pier was solid and acted as a unit and would impose a uniform load on the soil. Before any settlement could occur, the soil had to be compressed or flow from underneath the pier. The embankment, on the other hand, was capable of deformation and would not exert a uniform pressure on the soil. The heaviest pressure would come under the portion "BC", and if any settlement occured, the base would assume the form shown in the figure.



The pressure between the embankment and the soil would remain normal to the surface of contact, and it would therefore have a horizontal component. This would cause the soil to flow from underneath the embankment.

(16). EXPOSITION BUILDING, PARIS, FRANCE.

The methods used in this test are unique, and they must have been adopted more on account of the form of the loading material than for any

other reason. A perfectly level surface, in the form of a square, was prepared, on which was placed four cast iron blocks, 20 inches square, the distance apart being 11 feet and 8 inches, and these spaces were bridged by means of "T" beams. Additional "T" beams were piled on this framework until the load on the soil was 7.5 tons per square foot. At this point, indications of settlement were noticed, and this load was allowed to remain for 24 hours, when the settlement had increased to 10 1/4 and 11 inches. The loading was then continued until the pressure reached 8.1 tons per square foot, when the pressure had increased to such an extent that the "T" beams rested on the ground. It was assumed that the safe load was 5 tons per square foot, and that some settlement was to be expected when the load reached 7 tons per square foot. No data as to the ultimate stabilty of the structures erected under this assumption could be obtained.

(17). CHURCH OF DIVINE PATERNITY, NEW YORK.

Tests on the foundations of the Church of Divine Paternity in New York were conducted under the direction of Mr. Foster Crowell, the architect. The tests were made on a stiff gravelly clay, 20 feet below the natural surface. The platform on which the test load was placed was supported by a wooden post, 1 foot square. The platform was loaded until the pressure reached 7.62 tons per square foot. At the end of 18 hours the settlement was 1 5/4 inches, and at the end of 46 hours it had increased to 2 11/16 inches. A second test was made using a pressure of 5 tons per square foot, and no settlement was noticed for 47 hours. The pit in which the test was conducted was then pumped dry, and a settlement of 1/8 inch was noted. 5 tons per square foot was assumed as the safe load.

(18). SAND FOUNDATION, NEW YORK.

A test on the sand foundation of a New York Department Store was made by Mr. Foster Crowell as follows:-

A pier, 14 feet square, resting on fairly good clean sand, was constructed and loaded with a weight of 789 tons or 4.05 tons per square foot. A settlement of .085 inches was noted at the end of 5 days, and the load was allowed to remain for 6 days more without further settlement.

(19). NATIONAL BANK BUILDING, TORONTO, CANADA.

The City of Toronto, Canada, is located in the bed of an old lake, and the underlying strata are composed entirely of clay. Before designing the foundations of the Trader's National Bank of that city, Mr. Brainard conducted several tests on the bearing power of the clay. A pit 20 feet deep was dug. The clay was hard on top and gradually softened as the excavation deepened. At the depth of 20 feet, the clay was very soft, resembling putty. Great care was taken to prepare a horizontal bearing area, and a timber, 1 foot square, was rested on this, and the load was placed on a platform attached to the top of the timber. A level was sighted on a gauge rod, projecting above the loading platform, and the platform was quickly loaded. No settlement was noted until the load reached 2 1/2 tons per square foot. At this point a settlement of 5/8 inch occured, and the loading was discontinued. The load was allowed to remain for 12 hours, when the settlement had increased to 1 1/2 inches. Some upheaval around the base of the mast was noted.

A second test intended to approximate actual conditions was made. An 8-inch pipe with the outside edge beveled to 45 degrees was driven 8 inches into the bottom of the pit. An oak plunger which was just small

enough to insure absolute clearance was fitted into the pipe. This plunger projected above the pipe and carried a loading platform. This was loaded until the pressure reached 5 tons per square foot and no settlement was noted.

The foundations were designed for a pressure of 4 tons per square foot. No description of the present condition of this foundation can be found.

(20). EXPOSITION BUILDING, COLUMBIAN EXPOSITION, CHICAGO, ILL.

The buildings of the Columbian Exposition were located in Jackson Park, Chicago, Ill., where the surface soil is composed of sand and filled in ground. The whole site is underlain by a strata of clay, and hardpan is found at depths varying from 26 to 56 feet. Since most of the Exposition buildings were of a temporary nature and would not justify the expense of carrying the foundations to any great depth, Mr. Gottleib, the Chief Engineer, conducted a series of tests on the surface soils. Platforms, 5 feet square, were constructed, placed upon the surface to be tested, and gradually loaded with pig iron. In testing the sand, a load of 2 1/4 tons per square foot was used and the maximum settlement observed in any case was 5/8 inch. Tests on the loam showed that the pressure should not exceed 1 1/4 tons per square foot.

(21). STATE CAPITOL AT PIERRE, SOUTH DAKOTA.

The foundations of the State Capitol at Pierre, South Dakota are built upon gumbo. Gumbo is a form of clay, is very dusty when dry, and forms a stiff tenacious mud when wet. The gumbo was underlaid by a strata of very hard bluish shale which upon exposure to air or moisture disintegrated and formed gumbo. The bearing capacity of this soil was

unknown, and some tests were necessary before the footing could be designed. Test pits were dug to the depth required for footings and the soil tested by means of a timber, 1 foot square, carrying a loading platform. This platform was loaded until the pressure reached 3 tons per square foot. All of the tests gave practically the same results. The maximum settlement was 3/16 inch. One and one-half tons per square foot was assumed as the safe load.

(22). EAST RIVER BRIDGE.

The piers supporting the East River Bridge at New York rest upon a strata of very fine micaceous sand, underlaid by rock. Before the caissons were sealed, this foundation was tested by applying a pressure of 10 tons per square foot by means of a timber, 1 foot square. No appreciable settlement was noted.

(23). GOVERNMENT PRINTING OFFICE, WASHINGTON, D. C.

The Government Printing Office at Washington, D. C. rests on a strata of sand and gravel, saturated with water. Before designing the footings, tests were made by excavating pits inside of drums, 6 feet in diameter, and setting up timbers, 1 foot square, inside of these drums. These timbers were found to sustain loads of 8 to 10 tons without settlement. The safe bearing capacity was assumed as 4 tons per square foot, but the footings were designed for a pressure of 4 tons per square foot for live load and 3 tons per square foot for dead load.

(24). HENRY WORTHINGTON HYDRAULIC WORKS, HARRISON, NEW JERSEY.

The following description of soil tests, conducted by Messrs. Baldwin and Co. at the site of the Henry Worthington Hydraulic Works at

Harrison, New Jersey, was taken from an article published by Mr. Baldwin in the Engineering News.

"This plant is located on the Hackensack Meadows, the average level being 10 feet above sea level. It was the original intention to place the foundations before grading the land, but this was found impracticable on account of the soft ground, and consequently the ground was drained and graded before the trenches for foundations were opened. Extensive tests on the bearing power of the soil were carried on by Baldwin and Co., the engineers. The method used was as follows:-

"A pit was dug until a hard stratum was found. On this hard material, there was placed a vertical mast, one-tenth of a square foot in area. At the top it carried a platform, and it was kept vertical by means of guides on the surface of the ground. A card was tacked on the post, opposite one of the guides, and a line drawn on this card by means of a straight-edge placed on the guide. The platform was then loaded with a known weight of bricks, and a second mark made on the card. This process of loading and marking was kept up until there was an upheaval just beyond the edge of the post, and the post settled more rapidly with each increment of load. When this occured, a portion of the load was removed, and another mark was made on the card, which was frequently above those previously drawn. More bricks were taken off until no further settlement was indicated by a careful comparison of the marks. From the last figures, the load per square foot could easily be deduced, and assumed as the bearing capacity of the soil. The footings were then designed for 1/2 of this bearing capacity.

"When haste was necessary, these tests were carried on until the rate of settlement increased rapidly, and this was taken as the bearing

power of the soil."

Mr. Baldwin believes that tests, made in this way, compare with tests made on larger areas, and that the results are accurate.

(25) TESTING MACHINE,

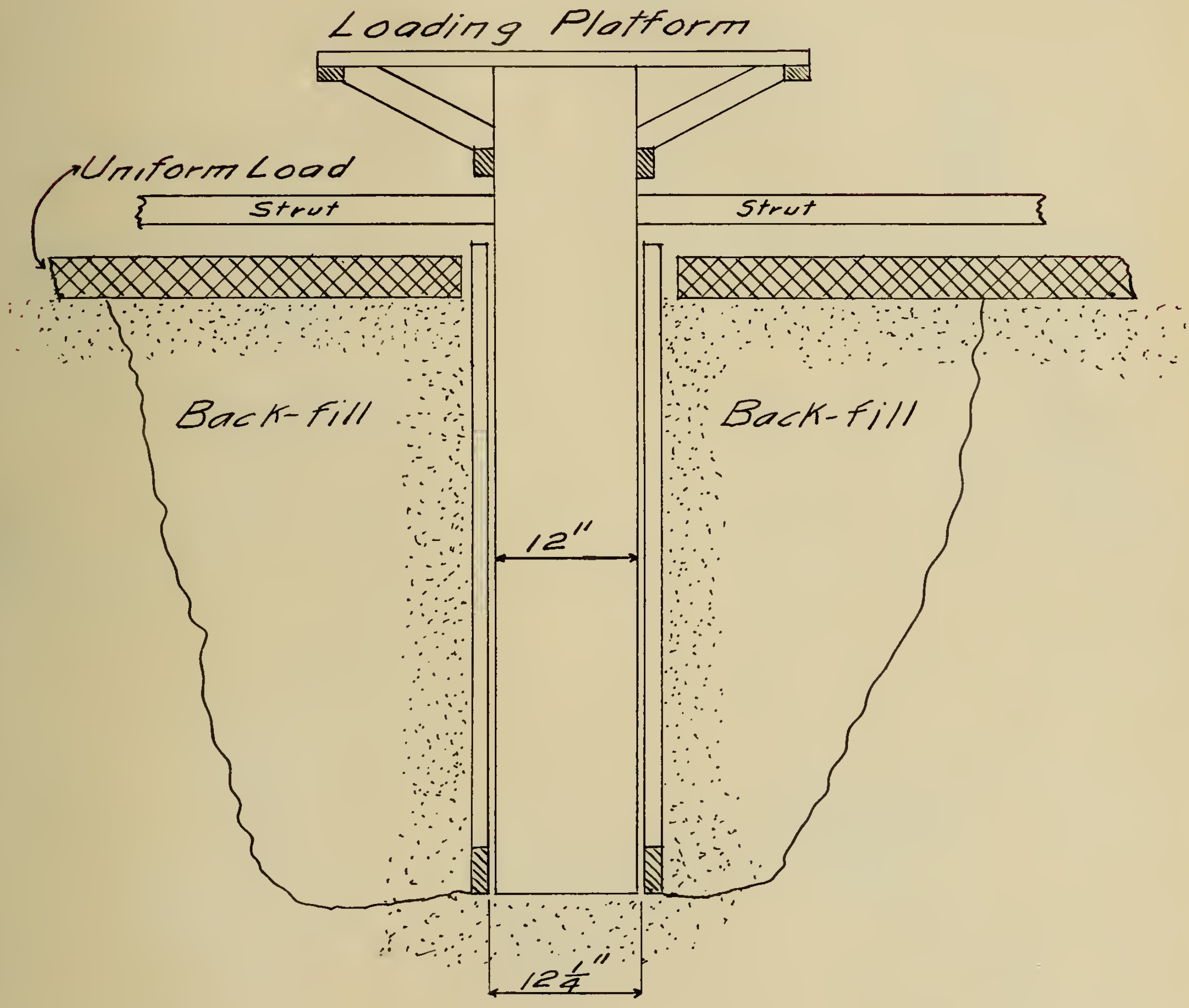
All of the tests which have been described heretofore, have been made by loading a certain area of soil and noting the corresponding settlements. The method of testing, devised by Mr. Mayer , derives the bearing capacity of the soil by comparison with some standard condition. The body of the instrument, used in making these tests, is a tube, and upon this slides another tube having a cross-head held by a strong spiral spring, fitted inside the main tube. The sliding tube can be moved by a pair of arms. A set of sounders of varying diameter are provided, any one of which can be screwed into the body of the apparatus. In use the apparatus is held vertical by the arms or handles, and the pressure is put upon it in a downward direction, and this pressure is gradually increased until the sounder enters the surface of the soil to a depth of one millimeter. The position of the slider is then noted on a scale which is graduated to read pounds. The bearing power of the soil is estimated from this value.

(26) TESTING MACHINE BY MR. BRAINARD.

The value of a soil test will be greatly increased if it can be made under conditions which resemble the final condition of the proposed foundation. In testing a sand foundation for a Department Store in New York, Mr. Brainard devised a method of testing which gave very accurate results. A pit was dug to the depth required for the foundations, and a rectangular box 12 1/4 inches square and 6 inches high was placed on the sand. The area around the box was covered with 6 inches of concrete. A mast 12 inches square, carrying a loading platform, was placed in this box, care being taken to see that the sand in the box was perfectly level. A box 12 1/4 inches square, extending above the natural surface of the sand, was then placed around the mast, and the sand was back-filled. The mast was loaded by placing weights on the platform and the sand was loaded with a uniform load of pig-iron. Results obtained by this method of testing agree very closely with the settlement of the finished structure. This apparatus is illustrated in Fig. 8.

Table 8.

Testing Machine Used by Mr Brainard in Testing Sand Foundations.



(27) MAGISTRATES COURT BUILDING, GEORGETOWN, BRITISH GUIANA.

The Magistrates Court Building at Georgetown, British Guiana, is founded in a strata of loam, underlaid by a strata of clay, 125 feet or more in thickness. The completed building imposes a load of 1066 pounds per sq. ft. on the soil and a settlement of 1/2 inch was noted when the building was completed. The settlement continued for about ten years when a slight rise occured. This is accounted for by the prevalent rains during that year. The soil is a very heavy clay which swells upon being wet. A record of the settlements of this building is given in Table 16 and in Diagram 22.

Settlement of Magistrates Court B'ldg. in British Guiana.

Pressure on Soil:- 1066 lb. per sq. ft.

Table 16

Date	Net Average Settlement in Feet	Heave in Feet	Total Settlement in Feet
First 4 yrs.	1.1175		1.1175
1896	.0930		1.2105
1897	.0399		1.2504
1898	.0380		1.2884
1899	.1888		1.4772
1900	.0628		1.5400
1901	.0356		1.5756
1902	---	.0057	1.5699
1903	.0164		1.5863
1904	--	.0690	1.5173

No Settlement Since

Foundation and Stratification

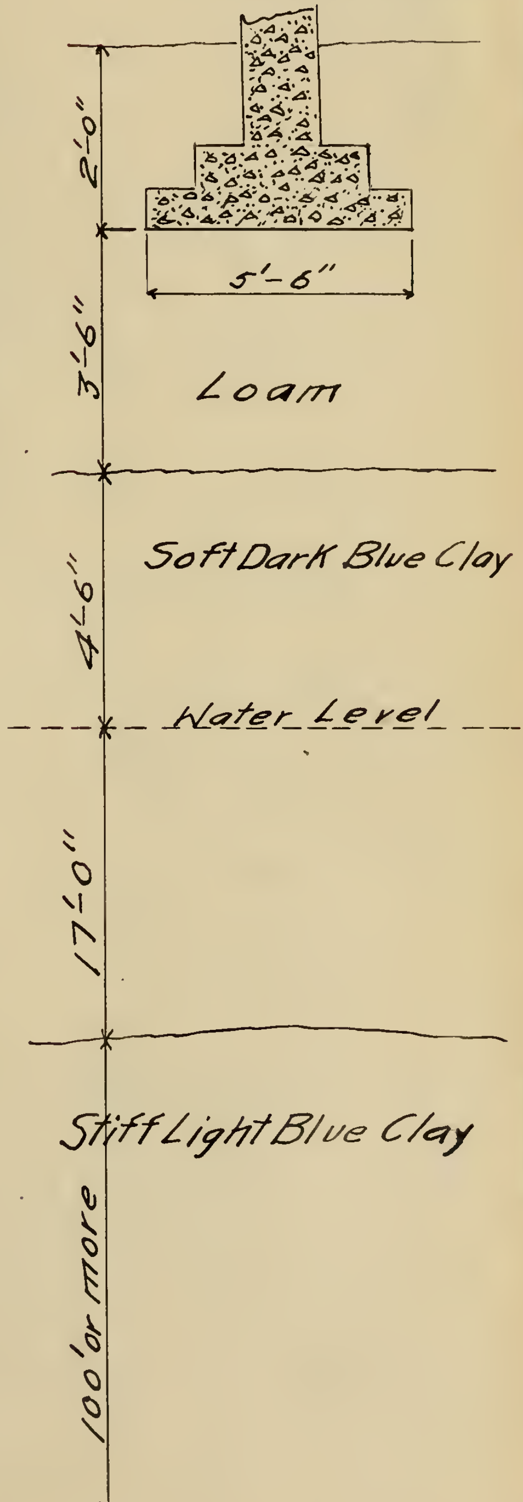
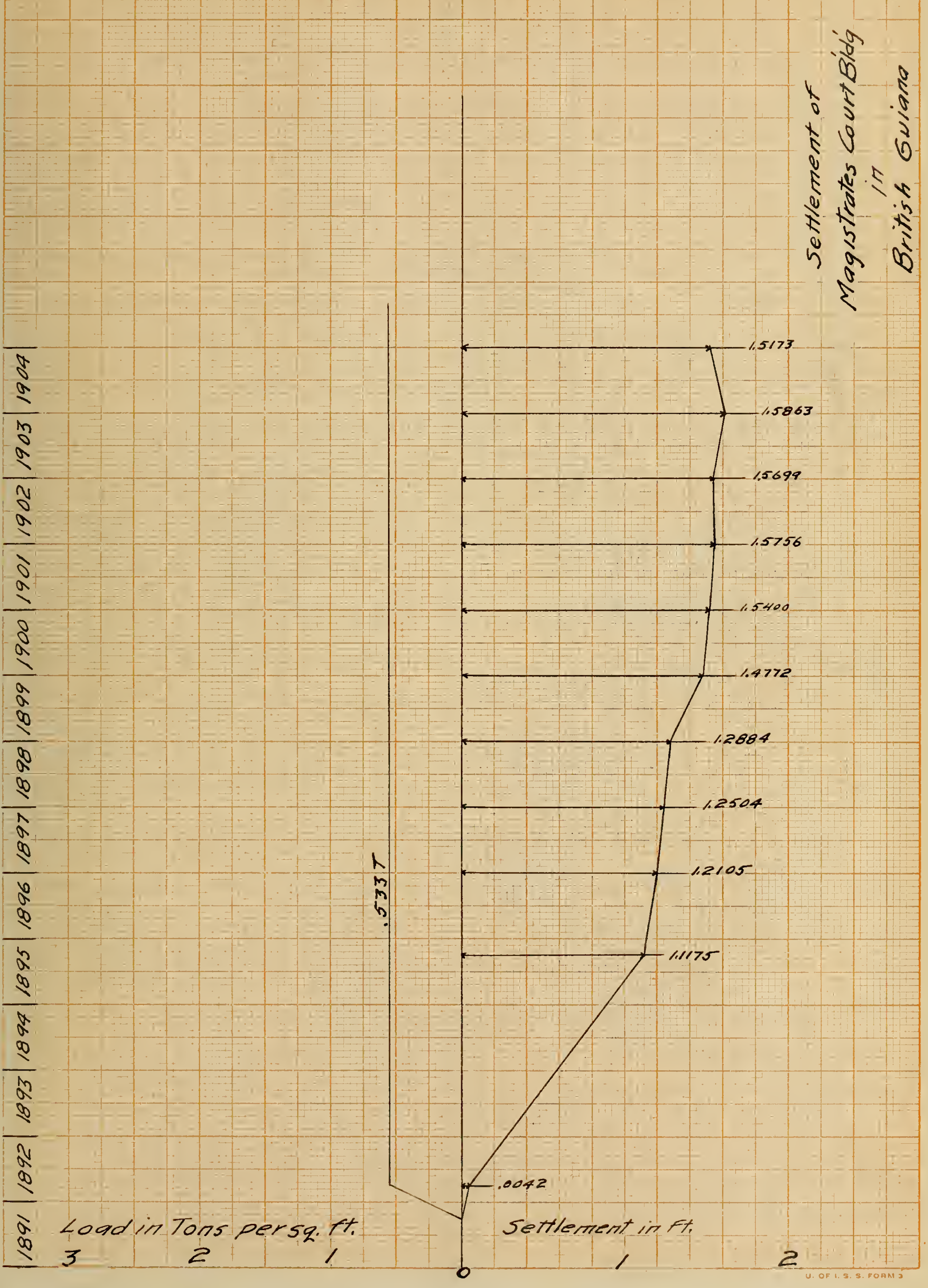


Diagram 22.


Settlement of
Magistrates Court Bldg
in
British Guiana
1.5173
1.5863
1.5699
1.5756
1.5400
1.4772
1.2884
1.2504
1.2105
1.1175
.0042
.533 T
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
Load in Tons per sq. ft.
Settlement in Ft.
3
2
1
0
1
2
U. OF I. S. S. FORM 3

(28) HOMEOPATHIC HOSPITAL, PITTSBURG, PENNSYLVANIA.

The Homeopathic hospital at Pittsburg, Pennsylvania, was built of brick, steel, and terra.cotta, and the height varied from four to six stories. The wall footings were 36 inches wide under the four-story part and 40 inches wide under the six-story part. They rested on a strata of hard, compact clay that was difficult to pick. This clay is locally known as hardpan. The foundations were examined and approved by Mr. C. Mueller, the architect, before any concrete was placed. Test pits 4 feet deep were dug, and the same clay was found as at the footings. Test pipes 1 1/2 inches in diameter were driven by 16-pound mauls and would penetrate only 4 feet. The foundations were designed so as to impose a maximum load of 8 tons per sq. ft. on the hardpan, but when the load reached only a little over 2 tons per sq. ft., the foundations showed signs of failure. Work was discontinued, and means were taken to stop the settlement, but before this was accomplished the settlement had increased to a maximum of 11 3/4 inches. The interior columns showed no settlement and the cellar floor rose 2 1/2 inches at the point of maximum settlement. Rainfall during the month previous to the settlement was excessive, and the trouble seems to be due to the fact that the surface drainage was not properly taken care of. A record of the settlements of this building is given in Table 17.

Table 17

Settlement of Homeopathic Hospital at Pittsburg, Pa.

Foundation in Hardpan   Load:- 2 Tons per sq. ft.

Date	Settlement in inches	
	North Wall	South Wall
June 2, 7 P.M.	$4\frac{3}{4}$	0
" 3, 9 A.M.	$8\frac{3}{16}$	$2\frac{1}{8}$
" 3, 5 P.M.	$9\frac{3}{4}$	—
" 4 4:35 P.M.	$11\frac{3}{4}$	$2\frac{9}{16}$
" 5 7:30 A.M.	$11\frac{3}{4}$	$2\frac{5}{8}$

PART 2.

RELATION BETWEEN SIZE OF BEARING AREA AND SETTLEMENTS.

No definite relation between the size of the bearing area and the settlements can be established from these tests, but in most cases they indicate that the unit bearing-capacity decreases with the size of the bearing area. This is especially true of loam and clay, and to a lesser extent it is also true of sand. This is best illustrated by Diagram 17, which was drawn from data obtained by Mr. John Roy in a test on the clay at New Orleans, Louisiana. A study of Diagrams 14 and 15 of the test loads and settlements for soil tests at the site of the State Capitol at Albany, New York, lead to the same conclusion. In this case the difference in settlements is not so great, but the greater regularity of the settlement of the mast with an area of one sq. yd., as compared with that of the mast with an area of one sq. ft., is very noticeable. Judging from Diagrams 14 and 15, two tons per sq. ft. would certainly appear to be a reasonable value of the safe working pressure, but the fact that the foundations constructed under this assumption are at present in an unstable condition, proves that the unit bearing capacity decreases with the size of the area. Tests at the site of the Municipal Building in New York City show the same results, but in this case the first test was performed in such a manner as to eliminate skin friction, while the second test was obtained on a finished pier and skin friction played an important part.

The manner in which pressures are transmitted through the soil is unknown, but it is probable that when pressure is applied to the soil by means of a mast, the lines of pressure form a cone, the slope of the

sides being some function of the angle of repose of the soil tested. If a foundation be considered as being composed of a number of smaller areas, it can be seen that the cones of pressure would interfere, thereby reducing the comparative bearing capacity of the soil.

As the size of bearing area increases, the ratio between the perimeter and the area would decrease, and the comparative reduction of the shear along the outline of the bearing area and of the skin friction would also cause the unit bearing capacity to decrease.

RELATION BETWEEN SHAPE OF BEARING AREA AND SETTLEMENT.

Diagram 18 shows that the settlement of a mast, 1 inch by 16 inches, carrying a load of 102 pounds per sq. in., is much less than that of a mast, 4 inches square, under the same load. In this case the reduction in the ratio between the perimeter and the area is very marked, and the greater settlement of the square mast would be due to the reduction in shear and skin friction.

RELATION BETWEEN TIME AND SETTLEMENT.

The relation between time and settlement is very important as it determines the rate of settlement. When a load is first applied to a soil, the settlement usually occurs in a short interval of time, and if the load is allowed to remain, the settlement will cease. This indicates that the soil is compressing, and as the load approaches the maximum bearing capacity of the soil, the intervals of time before the load comes to rest will increase. When the bearing capacity of the soil has been reached, the settlement will be continuous. If equal increments of loading are used, and the settlements are measured at equal intervals

of time, a curve can be drawn so that the slope of the curve represents the rate of settlement. The data for Diagrams 1 and 2 were obtained in this manner, and these Diagrams show that the settlement was uniform until the load reached 11 tons per sq. ft. and that when this point was reached, the settlements increased in greater ratio than did the loads. The maximum bearing power of the soil is therefore assumed as 10 tons per sq. ft. Although the data for Diagrams 3 and 4 were not obtained with any special reference to equal increments of loading and equal intervals of time in noting settlements, they show that the rate of settlement increased as the load approached 11 tons per sq. ft.

RELATION BETWEEN LOAD AND SETTLEMENT.

In general, it may be said that the settlement increases in proportion to the load until the bearing capacity of the soil is reached, and that after this, the settlement is more rapid. In Diagrams 1 and 2, the total settlement for each increment of load is indicated by the slope of the curve, and this remains fairly constant until the load reached 11 tons per sq. ft. At this point, the curve shows that the increment of settlement increased rapidly and 10 tons per sq. ft. is assumed as the safe bearing capacity of the soil.

RELATION BETWEEN PERCENTAGE OF MOISTURE IN THE SOIL AND SETTLEMENT.

The bearing capacity of clay decreases as the percentage of moisture increases, but this is not as noticeable as might be supposed. Diagram 3 shows that rain fell on the second, third, eighth, and eleventh days of the test and that these rains did not increase the settlement. This might have been due to the fact that the clay was saturated before these rains fell. Diagram 4 shows that when the load had reached 6.95

tons per sq. ft., a rain of 1.09 inches fell and that this caused a great increase in the settlement. A few rains had fallen previous to this, but they were all light, and it is probable that the clay did not become saturated by these rains. Diagrams 1 and 2 show that the settlement decreases as the soil becomes dry. Test 1 was made while the percentage of moisture in the clay was 19.8, and the settlements shown by this diagram are slightly greater than those shown by Diagram 2. The data for Diagram 2 were obtained when the percentage of moisture in the clay was 17.

FACTOR OF SAFETY.

If the exact bearing capacity of the soil and the relation between the bearing capacity of the area tested and that of the finished foundation could be determined, a low factor of safety could be used, but as these factors are indeterminate a high value must be used. If the bearing capacity is determined in a manner previously described a factor of safety of 2 or 3 should be used. The choice of the proper factor of safety will depend somewhat on the shape of the load-settlement curve and the character of the structure to be erected.

TESTING MACHINE.

The choice of a testing machine will vary with the local conditions and the material available for loading. The apparatus used by the author is the most convenient to use as the handling of weights is eliminated, but it possesses the disadvantage of a high first cost, and would not be used unless a number of tests were to be made. This apparatus is illustrated in Figs. 1, 2, and 3. The apparatus illustrated in Fig. 6 possesses the advantage of a low first cost and is to be recommended where only one or two tests are to be made. Fig. 7 illustrates a very

novel testing apparatus, and for small tests, this is the cheapest machine to build. The weight of this machine is very small, and it can be moved by one or two men. This apparatus is not adapted for tests of large bearing area, and for this reason, the apparatus illustrated in Fig. 6 or a modification of this design is recommended.

For tests at great depths below the surface, the testing apparatus illustrated in Fig. 4 is recommended.

PART 3.

SUGGESTIONS FOR FUTURE EXPERIMENTS.

The writer is of the opinion that this subject is not suitable for a student thesis. The time which an undergraduate can spend on experimental work is limited, and if future tests are to be conducted in the manner in which they have been in the past, 1 to 2 weeks will be required for each test, and only a few tests can be made each year. As a great number of tests are necessary before any conclusion can be drawn, it is apparent that an undergraduate is not in a position to do justice to this subject. The weight of the apparatus is so great that it requires 4 or 5 men to set it up properly, and this also handicaps an undergraduate in the performance of tests.

More satisfactory results could be obtained if the following suggestions were carried out:

1. Assign this thesis subject to 4 or 5 men. It would require this number to handle the apparatus and they could arrange their time so that a continuous record of the settlements could be obtained.

2. In making tests to establish the relation between size of bearing area and settlement and between shape of bearing area and settlement, make the tests of one day's duration, adding equal increments of load and keeping a continuous record of the settlement.

3. Use an automatic recording apparatus for recording the settlement. This apparatus can be constructed by fastening a pencil to the mast, and having a strip of paper, moved by clockwork, so arranged that the pencil would make a continuous mark on the paper.

4. In making longer tests to determine the bearing capacity of the soil, add equal increments of load and let the apparatus come to rest before adding further load. The rate of settlement and the settlement due to each increment of load can then be obtained.

5. Determine the relation between the percentage of moisture in the soil and the settlement by making tests of one day's duration after a rain has fallen.

FINIS.